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A QUESTION OF UTILITY

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In accordance with the 1988 Army Aviation Modernization Plan, the Army entered contractual agreement to begin acquisition of 2,253 UH-60 utility helicopters to replace approximately two-thirds of the 3,147 UH-1 aircraft destined for retirement. The plan foresaw the newer aircraft assuming the majority of the utility mission with the residual balance of UH-1 helicopters assuming a supplementary role. Because of subsequent budgetary considerations, the decision was reached to stop purchasing replacement aircraft after the close of Fiscal Year 91. By that time the Army's total procurement will have reached 1,147 aircraft, considerably short of the established target. Army planners now face the difficult task of reconfiguring the utility fleet with available assets to satisfy future service needs.

Although not immediately obvious, this new challenge has arisen at a fortuitous moment. Recent political changes manifest within the Warsaw Pact nations and the Soviet Union have clearly vindicated our strategy of preparing for war in Europe to prevent its onset. Threat analysis now suggests that the most likely use of US military force resides in the low intensity conflict (LIC) theater. Recognizing that the UH-60 was designed to prosecute mechanized war, the question of its application to LIC rests largely on speculation. Now, before irrevocable decisions are made to retire the majority of the UH-1 fleet, the Army must determine which of the two aircraft will better serve our future needs. Another environment-technology mismatch reminiscent of the aborted hostage rescue attempt would be inexcusable.

As a preliminary comparison a semi-Markov process was formulated to forecast performance of both aircraft in desert, mountain and jungle environments during day and night conditions. The model incorporated segments from five standard utility helicopter missions into a Markov chain and predicated eight different measures associated with survivability and mission accomplishment. The results were somewhat surprising.

All factors relating to survivability confirmed the UH-60 the superior aircraft throughout the entire range of scenarios. This conclusion is consistent with UH-60 design specifications relating to crashworthiness and ballistic tolerance which were specifically established to correct deficiencies noted in the UH-1 during the Vietnam War. However, concerning mission accomplishment, the UH-1 proved to be the better aircraft across all environmental variations. Similarly, when operational costs of the two helicopters were compared, expenses associated with the UH-60 were twice those of the UH-1.

The main impact of these findings concerns the fact that neither aircraft emerges the clear winner. This analysis can be easily expanded to perform a more thorough comparison based upon measures selected by Army leadership. Armed with such results, the Army can make informed decisions regarding the future composition of the utility fleet.

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A Question of Utility

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ABSTRACT

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The main impact of these findings concerns the fact that neither aircraft emerges the clear winner. This analysis can be easily expanded to perform a more thorough comparison based upon measures selected by Army leadership. Armed with such results, the Army can make informed decisions regarding the future composition of the utility fleet.

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I. THE INTRODUCTION

"With 2000 years of example behind us we had no excuse, when fighting for not fighting well."

T.E. Lawrence

The US Army is charged with two fundamental and complementary tasks. First, it must deter armed aggression directed against the nation or its vital interests. And second, should deterrence fail, it must quickly subdue the aggressor while containing the scope of the conflict. To accomplish these objectives, the Army must assemble, train and maintain a standing force capable of engaging potential enemies in any conceivable part of the world.

Because the government constrains the size and cost of its armed services, the Army cannot build an organization capable of defeating all possible adversaries. Limiting assumptions must be made regarding the probable identity and capabilities of the threat. Since the end of World War II, the Soviet Union has been our primary enemy. Alliances have been formed and contingency plans prepared specifically to contain the influence of a hostile Soviet Union. As clear evidence of US resolve, portions of six mechanized divisions are deployed in the European Theater and, of its eighteen active component divisions, ten are mechanized infantry or armor, designed for high speed maneuver in European terrain.

However, recent events have prompted the Army to reevaluate probable threats. The rapid rise of nationalism among Third World nations coupled with a less belligerent Soviet Union suggest that future American military involvement is most likely in the realm of low intensity conflict (LIC). Though the Army has experience in this environment, its equipment inventory remains essentially designed for mechanized war. Even light infantry divisions, touted as American specialists in LIC, were conceptually designed to rapidly reinforce mechanized forces in the European and Far Eastern Theaters. In light of recent developments the logical question to ask is 'Can equipment designed for mechanized war be readily adapted to LIC?'

Accordingly, the purpose of this thesis is to evaluate the performance of current military equipment in LIC missions. Two helicopters will be compared, the aging UH-1

Iroquois, a relatively simple general purpose transport, and its planned replacement, the UH-60 Black Hawk, a more technically sophisticated aircraft. This comparison will match the performance and costs of each aircraft under a variety of conditions and will hopefully offer insight regarding the use of technically complex equipment in the LIC environment.

The paper begins by recounting the events which prompted a review of our military posture. It examines various factors basic to the comparison by describing the LIC environment, primary missions assigned to utility helicopters and technical aspects of the two aircraft. Next, the paper introduces the semi-Markov process as a versatile, analytic tool, defends its selection to predict aircraft performance and uses elements of the preceding sections to formulate a feasible state space. Finally, using measures of effectiveness generated by the stochastic analysis, the paper concludes with a detailed analysis of the performance and cost projections for each modeled aircraft.

II. THE CATALYSTS

"Nothing endures but change."

Heraclitus 540-480 B.C.

That ours is a world of change is not a new idea; change is a theme which pervades the very fabric of the industrialized world. One has only to recall clamoring groups of people, impatient for a cure for Acquired Immune Deficiency Syndrome to realize that in our society people expect change. What is surprising, however, is the enormity of change in our present age. In 1992 twelve European nations will enter an economic union which will parallel in many ways the formation of a new nation-state. In strife-torn Nicaragua, Communist leader, Daniel Ortega, was peacefully replaced by Violeta Chamorro as president in a free election. And Soviet leaders and representatives of aggrieved constituents have entered discussions which could conceivably lead to peaceful secession of republics from the USSR. These and other developments have profoundly altered the economic and security environments facing the US, prompting its Armed Forces to reassess the nation's potential advisories as well as its ability to prosecute strategic objectives.

Contemporary US defense strategy has habitually emphasized two extreme military contingencies. The first involves an unprovoked conventional assault launched by members of the Warsaw Treaty Organization (Warsaw Pact) against Western Europe while the second encompasses a preemptive nuclear attack by the Soviets against US strategic forces throughout the world. Though many American politicians draw clear distinctions between the two possible scenarios, most North Atlantic Treaty Organization (NATO) officials consider the two corporately. The Warsaw Pact forces enjoy a clear numerical advantage in men and materiel over their NATO counterparts, and should conventional war ignite between the two alliances, many Europeans believe that without nuclear intervention the NATO forces would be rapidly overrun before sufficient reinforcements could arrive from North America. Ultimately, they rely upon NATO's nuclear arsenal and the threat of its use against the Soviet homeland to deter conventional as well as nuclear aggression [Ref. 1: p. 33].

Ironically, past experience suggests that the Soviets have no inclination to instigate a direct confrontation with the US. Since the construction of the Berlin Wall and resolution of the Cuban Missile Crisis, the Soviet Union has been content to achieve incremental advances throughout the world by use of aid and occasional military force. Following this practice, the Soviets have achieved notable gains among Third World nations, much to America's chagrin. It would appear that a national defense strategy emphasizing punitive use of nuclear weapons in both a conventional and nuclear context is ineffectual in circumstances where national objectives are limited and military action can only be applied with considerable political restraint [Ref. 1: pp. 33-4].

Such a defense strategy grows even more cumbersome in light of recent international political changes. During the 1950s and 1960s US containment of Soviet global influence was grounded upon the 'domino theory' which maintained that the fall of a key democratic government to Communists would precipitate subsequent Communist takeovers of neighboring states. Belief in this assertion prompted US military intervention in Vietnam. Surprisingly, 1989 and 1990 have witnessed another domino effect as several Communist regimes have sequentially toppled in the wake of a massive democratic, nationalistic trend [Ref. 2: p. 18]. Most notable are the changes which have assailed members of the Warsaw Pact. Though an observer might be hard pressed to identify a specific incident which sparked the chain of events that have permanently altered the political complexion of Eastern Europe, two declarations by President Gorbachev had substantial effect.

Under Leonid I. Brezhnev, the Soviet Union reserved *the right to intervene militarily* to secure Marxist governments in jeopardy. This policy, termed the 'Brezhnev Doctrine', was used to justify the 1968 Soviet invasion of Czechoslovakia. In March 1989 amid a constitutional reform movement in Hungary, Soviet President Mikhail Gorbachev assured Hungarian Party leader Karloy Grosz that the Soviet Union would not interfere, effectively renouncing the Brezhnev Doctrine [Ref. 3: pp. 243-4]. In December of the previous year, Gorbachev had announced before the United Nations General Assembly that the Soviet Union would unilaterally withdraw 50,000 men from the German Democratic Republic, Czechoslovakia and Hungary by the end of 1990 [Ref. 4: p. 10]. On 25 April 1989 formal withdrawal of Soviet forces from Hungary actually began [Ref. 3: p. 332].

Buoyed by the assurance that internal politics would not be stifled by Soviet repression, Eastern Europe began to cast off its mantle of Communism. In Hungary the government's approval to form independent political parties inaugurated the means to challenge the ruling Socialist Worker's Party for governmental control. Though other Soviet-bloc nations previously boasted multiparty systems, their rival parties were inevitably Communist-controlled [Ref. 3: p. 11]. In conjunction with a May 1989 decision to relax travel restrictions, Hungary began dismantling the barbed wire fence which marked its border with neutral Austria [Ref. 3: p. 343]. Later in October at the 33rd anniversary of the 1956 popular uprising, acting President Matyas Szuros declared Hungary a free republic, pledging that "The Hungarian republic is going to be an independent, democratic and legal state in which the values of bourgeois democracy and democratic socialism are expressed equally, ..." [Ref. 3: p. 807].

This democratic fervor was certainly not limited to Hungary. Within the short span of two years, Communist regimes in Poland and Czechoslovakia were peacefully removed through national election and replaced by multiparty systems. Bulgaria, remaining under Communist leadership, also passed legislation authorizing multiparty elections [Ref. 5: p. 248]. Amid a bitter civil uprising in Rumania, Communist Party leader Nicolae Ceausescu and his wife were overthrown and executed in December of 1989. An interim government assumed provisional control promising sweeping democratic reform which has yet to be realized [Ref. 3: p. 957].

Equally dramatic are developments in the German Democratic Republic. In an address in the Federal Republic of Germany on 31 May 1989, President Bush declared that "... Europe would only become 'whole and free' if the Berlin wall were torn down ..." [Ref. 3: p. 394] ; in November of that same year it occurred. Since then exclusive parliamentary control by Communists has been broken, multiparty elections have occurred and progress toward the country's economic and political union with the Federal Republic of Germany proceeds apace.

Nor is the Soviet Union immune from the effects of nationalism. Encouraged by the political turmoil of Eastern Europe, many of the Soviet republics have openly demonstrated their desire to secede from the parent union. By the end of May 1990, all three of the Baltic Republics of Latvia, Lithuania and Estonia had declared independence from the Soviet Union. To emphasize its declaration, Estonia had changed its national title, adopted its own flag [Ref. 5: pp. 345-6] and abolished the military draft [Ref. 5: p. 275]. Ethnic violence and secessional aspirations have also risen in the Kirgizia, Georgia and Azerbaijan Republics. And a most revealing picture was sketched by the results of the Soviet parliamentary elections held last March. Though clearly not pluralistic in an American sense, the election voiced dissatisfaction with current practices as candidates representing anti-party and anti-KGB platforms won seats [Ref. 6: p. 20].

Undoubtedly, profound change has occurred in the Soviet Union. Though the USSR remains America's most serious military threat, President Gorbachev's actions tend to mitigate his nation's belligerent posture. The Soviet military withdrawal from Afghanistan and proposed unilateral force reductions are consistent with the General Secretary's announced intentions to shift national production to the consumer goods sector. Also, the degree of political self-determination recently afforded Eastern European nations implies that Soviet military intervention in foreign governments, as occurred in Hungary (1956) and Czechoslovakia (1968), is no longer deemed viable.

This Soviet military retrenchment is also reflected in their enthusiasm to enter nuclear and conventional arms control negotiations. With the ratification of the Intermediate-Range Nuclear Forces Treaty, the US has enhanced its security by securing three lasting objectives. First, all US and Soviet ground-launched ballistic and cruise missiles with functional ranges within 500 and 5,500 kilometers will be completely eliminated. Second, a precedent was established regarding asymmetrical reductions to a level of mutual equality. And finally, verification procedures which virtually preclude intentional treaty violations have been formally commissioned [Ref. 7: pp. 1-13].

An unfinished legacy from the Reagan administration, the Strategic Arms Reduction Talks (START) Treaty may be concluded imminently. Such an agreement would effect actual reduction of nuclear arms by restricting nuclear warheads and delivery vehicles. Even as the technical enumeration and verifications details governing the initial agreement are resolved, proposals for a subsequent START treaty are being formulated [Ref. 8: pp. 1-2].

Within the broader scope of the European community of nations, the 1986 Stockholm Document of the Conference on Confidence and Security Building Measures and Disarmament in Europe has greatly contributed to maintenance of harmony between the members of NATO and the Warsaw Pact. The document prescribes announcement of major military exercises and authorizes observers to monitor and inspect military exercises. This agreement was a precursor to the Conventional Armed Forces in Europe (CFE) negotiations initiated in March 1989 [Ref. 7: pp. 1-13].

The CFE talks represent an attempt by NATO and the Warsaw Pact to asymmetrically reduce conventional armament to equal levels within Europe. The agreement addresses several weapon system categories to include tanks, armored personnel carriers, artillery, helicopters and combat aircraft, assigning compulsory limits as well as verification procedures [Ref. 7: pp. 1-13]. Though Presidents Bush and Gorbachev had anticipated a finalized agreement prior to the close of 1990, technical stipulations concerning the different types of weaponry and the need for mutually satisfactory verification procedures may delay the treaty's conclusion beyond the new year.

Reduction and an eventual ban of chemical weapons is also being pursued on a bilateral basis with the USSR and internationally at the Conference on Disarmament in Geneva. Though progress toward a worldwide ban on chemical weapons possession is plodding, an agreement with the Soviets to destroy portions of both nation's stockpiles may be imminent [Ref. 9: pp. 1-2].

Together, arms control advancement and the changing political clime in Eastern Europe have vastly altered the security environment facing the US. Accordingly, the US has seriously begun to reexamine its national priorities, making adjustments as appropriate. Driven by a large aging segment of the population, more resources are being channelled to social programs. And the easing of international tension has enabled Congress to focus attention upon reducing the national debt. Congressional resolve regarding deficit reduction is evident by its enactment of the Balanced Budget and Emergency Deficit Control Act of 1985, better known as 'Gramm-Rudman-Hollings'.

This legislation constituted a procedural rule by which deficit reduction would occur automatically if appropriate restraint was not otherwise exercised in the annual budgetary process. The bill specified compulsory budget reductions from 1986 through 1990 leading to a balanced budget in 1991. In the event a budget proposal exceeded the specified ceiling, the President was obliged to effect mandatory reductions applied equally between defense and domestic programs to bring the budget into compliance with the statutory ceiling. Further, nearly two-thirds of the domestic programs were exempted from automatic presidential reduction measures, placing a proportionally greater onus of responsibility for deficit reduction upon the Department of Defense (DoD) [Ref. 10: pp. 96-7].

From the Army's perspective the thrust of this measure translates into a substantially reduced organization. Consequently, beginning with the Fiscal Year (FY) 91 budget proposal, the Army plans to condense and reshape its force structure by means of selective reduction and reorganization to a revised design stabilizing in 1995. The implementation of this plan has already begun [Ref. 7: pp. V-3].

In May 1988 Defense Secretary Carlucci formed a commission to examine all DoD bases within the US and recommend closures and realignments which would generate base operations savings and eliminate excess property. The group recommended that operation of 91 bases be curtailed or closed. The commission's findings were endorsed by Secretary Carlucci, sent to Congress to be either approved or rejected in their entirety and subsequently became public law [Ref. 3: p. 5].

In consonance with reduced funding levels, equipment modernization programs have been stringently adjusted. Funding for the Army Helicopter Improvement Program and the Improved Recovery Vehicle was completely withdrawn. Annual procurement of Mobile Subscriber Equipment and the AH-64 Apache will be reduced with termination rescheduled to FY 91. Ongoing procurement of several other systems, to include the UH-60A Black Hawk, has also been reduced [Ref. 11: p. addendum].

For FY 91 the Army must reduce its total active component troop strength to 727,000. In order to comply, Secretary of the Army Stone has proposed several adjustments. Initially Secretary Stone wishes to deactivate the 2d Armored Division at Fort Hood, Texas and reduce the 9th Infantry Division stationed at Fort Lewis, Washington to a motorized brigade. Coincidentally, he proposes transferring the 7th Infantry Division to Fort Lewis, closing Fort Ord, California and moving a mechanized division from the Federal Republic of Germany to Fort Hood. Other planned personnel reductions involve an armored brigade at Fort Knox, Kentucky and an artillery battalion at Fort Stewart, Georgia [Ref. 7: pp. V-3-4].

Earlier this year Defense Secretary Cheney proposed closing more than 80 military bases in addition to those previously approved by Congress. In conjunction with his most recent tour of military bases in South Korea, the Philippines and Japan, he discussed with various allied government officials, withdrawal of American servicemen totaling 12,000 over the next two years [Ref. 5: p. 137]. When asked earlier concerning his long range plans, Secretary Cheney commented that subsequent Army reductions might amount to 135,000 troops [Ref. 5: p. 68]. Secretary Stone in a later interview indicated that the Army's active component strength reduction could be as high as 200,000 by 1995 [Ref. 11: p. 1].

The cumulative impact of reduced funding, arms control and the evolving security environment is generating profound change within the Army. To remain effective, the force must adapt to present constraints and security risks. As the potential for military involvement in defense of NATO decreases, threats associated with underdeveloped nations draw greater attention. If, as a result of budgetary constraints and CFE negotiations, the forward basing of US forces is reduced, Army leadership may choose to modify the service's organization and equipment inventory to better address low intensity conflict (LIC) threats. With the bulk of the nation's equipment tailored to mechanized war, such a shift in emphasis would likely prompt an evaluation of equipment suitability relative to the LIC environment.

III. THE CONTEXT

"The Achilles heel of the capitalist economy lies in the colonies... sever the raw materials flow from the colonies and you cut the spinal cord of the empire."

V.I. Lenin

Although the Soviet Union's conventional and nuclear military forces remain the most tangible threat to US security, the probability of deliberate armed aggression between the two superpowers is small. Furthermore, contingent upon Chairman Gorbachev's announced unilateral withdrawal of Soviet forces from certain Eastern European nations, the chance of accidental confrontation is likewise reduced. The residual challenge to America's security lies in a variety of forms of organized violence collectively described as low intensity conflict (LIC).

Developed in the 1970s, the term, LIC, has drawn considerable criticism since its initial use. Many practitioners of war regard LIC as an unfortunate misnomer, arguing that it unduly mollifies the intensity of the violence which characterizes such conflicts. Indeed, often strife between contending political factions translates rapidly into fierce struggles for national survival. However, American responses to LIC imperatives have historically required neither national mobilization nor vast military resource expenditure, and compared to the national effort needed to sustain an actual conventional war, LIC demands are relatively small, hence the terminology [Ref. 12: p. 1].

LIC was created to denote a range of "politico-military activities" short of declared conventional war. Primarily associated with insurgency and terrorism and activities designed to suppress them, LIC is used by some authorities to encompass such conventional military engagements as the 1986 reprisal raid flown against Libya. Still others use the term to describe certain nonviolent military operations such as peacekeeping missions and security assistance programs. Despite the variety of opinions regarding definitive boundaries, LIC circumscribes an extremely diverse collection of political/military activities considered less extensive than conventional war. Trying to concisely characterize so diverse an array of operations which includes the terrorist truck bombing of the US Marine barracks in Beirut and the American invasion of Grenada, would invariably prove misleading, but certain attributes common to all forms of LIC differentiate it from conventional war [Ref. 12: p. 2].

First, low intensity conflicts cannot be resolved by the exclusive application of military maneuver and concentration of fires. They normally emphasize small unit, decentralized operations employing unconventional tactics and fluid, dismounted formations consistent with the terrain. Consequently, success cannot be achieved in short order; participants must invest considerable time to effect favorable results [Ref. 12: p. 3].

Second, low intensity conflict rarely involves the traditional confrontation of massed, uniformed forces on a recognized battlefield. The distinction between combatant and civilian is obscured, confounding enemy identification as well as established laws governing the conduct of war. Further, the traditional boundaries separating secure rear areas and front lines do not exist. Relying upon his ability to assimilate with the indigenous population, an insurgent soldier can attack virtually any lucrative target. Like the insurgent, most successful counterguerrilla operations involve platoon or squad sized units moving about with exposed flanks and an unsecured rear. Because groups operate relatively independently, attachment of engineer, logistic and fire support is necessary at small unit level to provide inherent self-sufficiency [Ref. 12: pp. 3-4].

Third, the central objective of low intensity conflict is to gain the support of the host population. Whether by persuasion or through duress, this pivotal concern must dominate formulation of all tactical plans. Past measures such as 'body counts' or captured weapons are irrelevant in the LIC environment; the degree of success achieved must be gauged by the loyalty of the civilian people and coincident alienation of the antagonist [Ref. 12: p. 4].

Fourth, each conflict is unique to its terrain, its people and its political circumstances and must therefore be examined at length and entered with tactics and strategy adapted to the specific circumstances involved [Ref. 12: p. 4].

Finally, low intensity conflict more than any other military action emphasizes political considerations. Though military intervention is by definition an exercise of political authority, probably in no other use of military force are political constraints so confining. In retrospect many crises favorably concluded will reveal that conflict resolution emerged less from military influence than from medical, police and economic support [Ref. 12: p. 4].

Though the term, low intensity conflict, is relatively new, the struggle it represents is not. Despite its poor performance in Vietnam, the US has successfully contended in this style of war since its revolutionary origin. During the nineteenth century, as pioneer settlement expanded west, the Army fought campaigns against such elusive foe as the Sioux Indians led by Crazy Horse. In 1900, the Army was called to Southeast Asia to suppress the Philippine insurrection led by Emilio Aguinaldo. Again in 1927, the US sought to restore order to strife-torn Nicaragua by dispatching US Marines to quell a civil uprising led by Augusto Sandino [Ref. 12: p. 1].

In the aftermath of World War II and the Korean War much of the LIC experience gained in earlier campaigns was lost as America reduced her armed forces. In 1965, as major deployments of American forces initially entered Vietnam, the US was again embroiled in a counterinsurgency. As time wore on and American casualties mounted, the public eventually realized that the war was being prosecuted ineptly. So vehement became the criticism of America's participation in the war that military aid to developing nations was stringently curtailed, and much of the US military infrastructure designed to support LIC operations was eliminated. The legacy of disappointment from Vietnam severely constrained US military use through the end of the decade of the 1970s [Ref. 12: p. 8].

Three trends in global politics finally arrested the decline of US military capabilities in the LIC realm.

- The Soviet Union initiated an aggressive program of intervention in conflicts among developing Third World nations. Many observers directly attributed Soviet adventurism in Mozambique, Ethiopia and Angola to American resistance to Third World involvement.
- International terrorism reached the forefront of media attention with spectacular plane hijackings, kidnappings and car bombings reminiscent of Japanese kamikaze pilots. American citizens abroad were falling victim to terrorist atrocities, and the federal government felt powerless to prevent or retaliate against such acts.
- In response to seizure of American nationals abroad, the armed forces demonstrated incompetence in effecting their release. The disastrous response to the seizure of the SS Mayaguez crew by pirates and the aborted rescue of US embassy hostages in Tehran stood in stark contrast to the internationally applauded successes of the West Germans and Israelis in similar situations [Ref. 12: pp. 8-9].

With the election of a Republican administration under Ronald Reagan in 1980, the national bias against involvement in Third World politics was reversed. Economic aid to Central American governments and forces aligned against Marxist rule resumed in earnest. From 1980 to 1988, the US provided over $6.3 billion in military and economic aid to El Salvador, Honduras, Costa Rica and Guatemala. Concurrently, support for the Contra guerrillas in their war against the Sandinista regime in Nicaragua was steadily supplied. Assistance was not limited to Central America. The US sent substantial aid to the Philippine government to strengthen its fight against two guerrilla forces. Weapons and supplies were sent to the mujahideen to support the expulsion of Soviet troops who had invaded their homeland in 1979, and support was channelled to guerrillas fighting Cuban forces in Angola. Also, funding for the Department of Defense enjoyed a dramatic increase. The Special Operations community was specifically targeted for expansion while, in addition, the Army formed four Light Infantry Divisions [Ref. 12: p. 11].

The Light Infantry Division was originally conceived as a strike force capable of sustaining limited operations in a variety of contingencies. To enhance its strategic mobility, the division's equipment was stringently limited to what an infantryman could carry on his back supplemented by a small assortment of wheeled vehicles to carry heavier weapons. The division's primary focus was directed to the low intensity realm of conflict in regions lacking a 'developed support infrastructure' [Ref. 13: p. 1] so lack of tactical mobility would not impede its ability to engage an opponent.

Surprisingly, its original architects claimed that the light division's lack of heavy equipment would not preclude its deployment to either Europe or the Far East in a reinforcing role of forward-deployed US ground forces. Proponents of the light infantry concept explained that given terrain which restricted trafficability of mechanized forces, the light units could, using cover, stealth and initiative, engage and destroy a motorized enemy. Nevertheless, the Army's primary capability for LIC resides within the Light Infantry Divisions [Ref. 13: pp. 1-2].

And what of the future? For a nation blessed with geographic isolation, abundant national resources and a large consumer market, recent world events should encourage the US to become more circumspect of international involvement and concentrate on domestic economic revitalization. With the 'Cold War' in Europe rapidly approaching political armistice, arms reduction talks proceeding apace and democratic patterns developing in former Communist strongholds, what remains to threaten US security? Experts respond in part by sighting evolving trends in LIC.

The modern representation of LIC stems primarily from three historic catalysts; modernization, Soviet adventurism and decolonization. Though modernization persists throughout the developing regions of the world, Soviet interest in the Third World has begun to wane. Similarly, contingent upon Namibia's independence, decolonization will have been virtually completed, and yet, the present-day level of regional world violence registers the spread of LIC despite reduction of its initial root causes. Three reasons explain the continued growth of this phenomenon [Ref. 14: p. 10].

First, enduring poverty propagates widespread discontent. In distressed areas of the world where sickness persists, dissatisfaction grows acute. Modernization which has spawned rapid urbanization leaves large concentrations of people unemployed, fomenting crime and civil unrest. The proliferation of modern communication and transportation accentuates the discrepancy between 'haves' and 'have nots' and fosters anger which is ultimately directed at the existing government [Ref. 14: p. 11].

Second, regardless of the future of Soviet intervention in Third World countries, sponsors of organized violence will remain. Many states today possess not only the motivation but the means to organize large scale rebellion. With exportation of the Soviet armament industry to aligned governments and the surplus of funds accruing from petroleum and narcotics trade, states such as Syria, Libya, Iran and South Africa are willing patrons of organized regional unrest [Ref. 14: p. 11].

And third, the constraints which originally held the level of violence below the conventional war threshold remain in place. From the insurgents' perspective, resource availability provides the major barrier to continued escalation, though the motivation to expand the conflict is ever present. Conversely, from the sponsor's standpoint, reluctance to risk superpower confrontation bridles their willingness to manipulate violence [Ref. 14: p. 11].

Where might low intensity conflict arise? The recent spate of current events suggests a variety of possible sites. With the retrenchment of the Soviet Union from Eastern Europe and the nationalistic fervor of republics within that country, demands for national sovereignty may soon echo those voiced by Latvia, Lithuania and Estonia. The prelude to possible collapse of the Soviet empire would certainly provide fertile ground for LIC. And regardless of their future, the Soviets will continue to incite insurgency outside their borders to further their national interests [Ref. 14: p. 12].

As Europe integrates its markets and industrialization continues elsewhere, competition for raw resources will intensify. Third World countries rich in raw materials may form cartels similar to the Organization of Petroleum Exporting Countries in order to exert collective economic pressure on industrialized nations who, in turn, may resort to LIC if alternative sources of production are not available [Ref. 14: p. 12].

Finally, tribal, ethnic, religious and racial strife will continue to foster unrest in regional disputes for the immediate future [Ref. 14: p. 12]. As new nations emerge and mature, internal dissent will occasionally be vented by organized violence. This particular source of unrest may assume a new character from that of the past. Previously, rural-based movements characterized by masses of people poorly armed and organized, depended upon mass support before being afforded serious government attention. But advancements in communication, transportation and weapons have considerably lowered the necessary threshold to endanger an incumbent administration. Today, even small, well-organized groups can create sufficient destruction to unseat tenuous governments.

This more recent development of insurgent capability deserves further attention. The historic guerrilla soldier travelled on foot, wore the clothes of a peasant and depended almost exclusively upon small arms. Some current insurgencies, notably the Sendero Luminoso in Peru and the New People's Army in the Philippines follow this pattern. However, examination of the Afghan mujahideen, the Farabundo Marti National Liberation Front in El Salvador and the Contras in Nicaragua confirms that sophisticated weapons are not the exclusive dominion of the government forces [Ref. 15: p. 44].

In the next decade, insurgent forces will yield greater firepower than their predecessors. Modern automatic weapons exhibit increased rates of fire while their size and weight have been substantially reduced making them much easier to carry and conceal. The M16 and AK47 automatic rifles are now commonplace in many guerrilla movements, and evidence of the Uzi machinegun and Ingram machine pistol has been reported during encounters in Central America. The insurgent arsenals have expanded to include such sophisticated weaponry as grenades, rockets and missiles. Where before massed small arms were used to attack aircraft, infrared missiles are now found to be more devastating. Guerrilla use of light anti-armor weapons also puts most government wheeled and armored transport at risk as well [Ref. 15: pp. 44-6].

Improvements have also been made in communication equipment. Thanks to the electronics revolution, transceivers which are reliable, rugged and compact, can be purchased at reasonable cost. Reliance upon the foot soldier to communicate instructions is now obsolete. Attacks can be concentrated more rapidly and with greater complexity than previously. Further, the security of the guerrilla is enhanced as scouts monitor enemy progress [Ref. 15: p. 46].

Additionally, as a result of refinement of recreational and sporting clothes and equipment, the austere lifestyle of the insurgent fighter has noticeably improved. Lightweight jungle clothes, boots and water repellent camping gear are readily available to most indigenous forces. Dehydrated food and primary medical supplies also enhance the soldiers hygiene and raise his dependability [Ref. 15: p. 46].

These advancements collectively represent a vast force multiplier with which the government force must contend. At times the insurgent may gain combat parity with his opponent and be less inclined to avoid a direct confrontation. Consequently, care must be exercised by the counterinsurgent as he assumes his mission. The advances in technology will serve his advantage to a point. However, the Soviet Union's recent experience in Afghanistan stands as a clear reminder that adapting inappropriate technology to this war can render disappointing results [Ref. 15: p. 46].

IV. THE MISSION

"It is not so much the mode of formation as the proper combined use of the different arms which will insure victory."

Jomini, 1838

Despite the penchant of many nations to assess military might through force-level comparisons, the simple aggregation of weapon systems is not an accurate measure of combat power. Ordinarily, a force's effectiveness is magnified when its components are combined in complementary roles. By integrating different weapons and organizations into a cohesive whole, limitations of one element can be compensated for by strengths of others. Then, as an enemy attempts to evade the effects of one weapon system, he becomes exposed to those of another [Ref. 16: p. 25].

This structuring technique, known at small unit level as forming combined arms teams and in higher echelons as task force organization, is not achieved by merely amassing a variety of weapons and soldiers. The group must be organizationally unified. As with a capable football team, each member must properly execute assignments coincident with those of his teammates in order for the team to advance. In effect, this design process represents a continuous cycle. When a weapon is introduced into the arms inventory, attempts to integrate it within the force, and thereby, gain advantage over potential enemies, begin. Unfortunately, the cycle often falters. Considerable trial and error generally attend attempts to evaluate new combat capabilities and subsequently merge them into a cohesive fighting fabric. Furthermore, commanders comfortable with capabilities proven in the past, mechanically apply dated techniques to succeeding struggles, ignoring the innovation and adaptation demanded by the present conflict. History is sufficiently littered with unsuccessful military trials as a cursory review confirms.

With the perennial advance of technology, the destructive potential of combatants has steadily risen. Spears and clubs gave way to pistols, rifles and cannon. Mules and horses were replaced by trucks and tanks, ditches and barricades by minefields and chemical contaminants, each substitution more lethal than its predecessor and each fraught with mishap in early attempts at assimilation. Military adaptation of aviation serves to illustrate this process.

Initially an outgrowth of the postal service, the airplane eventually assumed a broad role in combat as missions were matched to its expanding range of capabilities. One is readily reminded of the airplane's contribution to Allied victories in World Wars I and II with pictures of aerial dog fights, bombing formations and strafing runs. However, as with other technical innovations, the airplane's success was not unqualified, especially in the low intensity conflict realm.

Major limitations arose from the fact that airplanes were tethered to a system of long, flat runways. Technical enhancements increasing the speed and maneuverability of aircraft also increased the requirement for runway length and smoothness. Often, in underdeveloped nations where insurgency flourished, such facilities were unavailable and if constructed, provided lucrative targets for guerrilla soldiers. Also, the dependence of airplanes upon launch and recovery airfields has often frustrated their support of ground forces. Because of range restrictions, small aircraft had insufficient time to deliver effective ordnance upon assigned targets. Ironically, when long range heavy or medium bombers were summoned for support, the indiscriminate destruction associated with collateral damage estranged the indigenous population from the host government's civil efforts [Ref. 17: p. 27].

Despite difficulties associated with the airplane's adaptation to counterinsurgency, the most remarkable combat development of recent note in LIC occurred in aviation with the introduction of the helicopter. The unique capabilities of rotary-winged aircraft were well matched to the austere geographic extremes commonly associated with unconventional warfare. Areas far removed from fixed-base runways could now anticipate aerial support on a sustained basis. As early as the 1950s the British experience in Malaya demonstrated the helicopter's ability to rapidly deliver, supply and evacuate troops in the field. One British officer noted that "Without the very small force of helicopters we had in Malaya four times as many ground forces would have been required." [Ref. 17: p. 29]. In Kenya and Cyprus rotary-winged aircraft were employed effectively in psychological operations to broadcast government-sponsored propaganda. The practice of dropping leaflets usually presumes that the enemy soldier is literate, an often mistaken assumption. However, helicopters equipped with loudspeakers, flying slowly above the jungle floor, announcing the government's promises of fair treatment, repeatedly drew large numbers of defectors from the insurgent's ranks [Ref. 17: p. 29]. Even more significant was the helicopter's role as an airborne reconnaissance platform. The aircraft proved adept at locating and monitoring enemy troop movements and subsequently directing their engagement by friendly forces.

Notwithstanding their demonstrated value to counterinsurgent forces, helicopters have inherent limitations which the astute military planner will acknowledge. A review of five tenets relating to past British experience in low intensity conflict provides valuable insight concerning helicopter employment.

- While denying guerrillas sanctuaries and interdicting their supply lines are essential to an effective counterinsurgent campaign, this mission is unsuited to the exclusive use of aerial-delivered firepower. This is not meant to imply that aerial attacks are without effect. The American B52 air strikes in Vietnam aroused considerable fear within the insurgent ranks; nonetheless, the Ho Chi Minh Trail remained viable throughout the war's duration.
- Use of indiscriminate aerial firepower embitters the indigenous population while fostering sympathy for the insurgent cause.
- Slow airplanes and helicopters are valuable in this style of war due to their ability to transport ground forces and perform reconnaissance.
- Insurgent warfare is protracted. Use of less technically sophisticated and expensive aircraft poses a lower economic risk to nations involved in LIC.
- The measure of technical sophistication needed in aircraft participating in LIC depends primarily upon the armament of the insurgent forces [Ref. 17: pp. 31-2].

In sum, as one English author notes "... the main role for the air force in counterinsurgency was not so much striking against guerrilla bases as transporting and supplying the ground forces." [Ref. 17: p. 29]. In the US Army utility helicopters perform these tasks but are capable of several more. Which, then, of standard utility helicopter missions, will enhance the effectiveness of the combined arms team in the LIC environment? A panel of aviation experts selected five: aeromedical evacuation, resupply, command and control, search and rescue, and air assault.

a. Aeromedical Evacuation

Primary reliance for patient movement within the Armed Forces has been placed upon aircraft by Department of Defense directive. The Army has accordingly organized dedicated aviation units which combine a rapid and flexible utility helicopter with a medically trained and provisioned crew to accomplish transport of casualties. These 'air ambulances' are typically organized into detachments composed of six helicopters, which are tactically dispersed within brigade rear areas, or companies of twenty-five helicopters retained by corps.

An appreciation of the aeromedical evacuation mission is incomplete without an understanding of the medical treatment system which it supports. Aid stations within battalion rear areas, medical companies in brigade and division rear areas and field hospitals in the corps support area collectively provide care for the sick and wounded within a land theater of operations. Patients are dispatched to appropriate facilities by surface and aerial transport through an evaluative process termed 'medical regulation'. Medical regulating officers assigned to divisions and corps maintain current status of the capacity and capability of medical units within the theater of operations and direct casualty evacuation accordingly.

Though air ambulance support can be specifically assigned in conjunction with combat missions, requests are normally initiated on demand by the battalion aid station. In the event a casualty's injuries exceed the medical capability of the aid station or its ability to respond expeditiously, the aid station requests launch of a detachment air ambulance from its parent medical company. The evacuation can be accomplished from either the point of injury or the aid station. After securing the injured parties, the air ambulance crew describes the extent of injuries to the medical regulating officer exercising jurisdiction who determines the patient's destination. When injuries warrant hospitalization, the aircraft is either directed to the appropriate facility or to the supporting medical company where patient transfer is accomplished with aircraft dispatched from corps.

b. Resupply

The efficient handling of supplies is of primary concern to the logistics officer. His functional objective is to keep the forces adequately provisioned without the burdensome excess which could impede rapid movement. The sheer magnitude of this mission is suggested by information contained in Table 1 which enumerates daily consumption of supplies per man distinguished by supply class [Ref. 18: p. 3-4].

Table 1. FORECAST DAILY SUPPLY CONSUMPTION RATE IN POUNDS PER MAN

class I	class II	class III	class IV	class V	class VI	class VII	class VIII	class IX	class X	total
6.7	3.26	47.8	8.5	31.29	3.2	4.27	0.35	1.52	0.0	106.89

These figures must be increased by a factor of 2.4 during the first thirty days of a conflict. To support even a Light Infantry Division, these factors forecast a total daily consumption of 1,068,900 pounds or 1,282 short tons. The responsibility for moving and distributing this volume of freight is enormous, too large to be charged exclusively to a single organization. And in the domain of unconventional warfare, where 'secure rear areas' are nonexistent, self defense emerges as a vital component of the logistical mission.

Surface transport customarily satisfies cargo delivery requests, but frequently ground lines of communication are severed by enemy interdiction, obstacles and congestion. The carnage of war coupled with the exodus of refugees can quickly arrest most road-bound traffic while the thin-skinned cargo trucks used to move supplies are extremely susceptible to small arms ambush. Often, the pace of battle will simply outdistance the capability of surface transport. In such cases aerial resupply offers a comparatively less vulnerable and more mobile alternative to surface transport. In forces of division size and below, this function is discharged by the utility helicopter.

Consequently, the utility helicopter is often used to complement other means of transportation. Though their most common use entails moving personnel, equipment and supplies beyond obstacles or to areas inaccessible to fixed-wing or surface transport, utility helicopters frequently satisfy logistic surge and time-sensitive demands [Ref. 19: p. 4-2].

Air movements are administratively classified as either scheduled or unscheduled. Scheduled movements occur when air delivery offers the most efficient transport option for regular, repetitive requirements [Ref. 19: p. 4-2]. Nonscheduled missions arise from infrequent requirements such as unit reconstitution, personnel replacements and other unforeseen contingencies.

The two most common methods of cargo movement by utility aircraft are internal and external load operations; although under extreme conditions, supplies can be dropped after being rigged with energy-dissipating material or by parachute. If weight and volume permit, cargo is secured within the helicopter to avoid interfering with flight aerodynamics. However, when equipment dimensions exceed the helicopter's internal cargo capacity, loads are rigged externally. When feasible, supply-delivery missions are combined with retrograde operations to derive the maximum benefit from the airframe. Typical retrograde missions include evacuation of repair equipment, enemy prisoners of war, human remains, noncombatants and casualties [Ref. 20: p. 2-20].

c. *Command and Control*

The pace of contemporary warfare continues to substantiate Sun Tzu's maxim that "Rapidity is the essence of war." The speed which characterizes current military actions places added emphasis upon astute leadership. Wars once measured in years are now gauged in days. Each commander attempts to accelerate his decision-making process, forcing his opponent to lag behind the battle's momentum, reacting to the conflict rather than initiating actions of his own.

With the US Army's adoption of Airland Battle Doctrine, command and control is largely implemented with broad mission-type orders which "specify what must be done without prescribing how it must be done." [Ref. 16: p. 21] Accordingly, subordinates are afforded the tactical latitude to exercise personal initiative in an ever-changing battlefield. Despite the freedom afforded junior leaders, the commander cannot completely relegate the conduct of the battle to his subordinates. Changes in the commander's intent will occur during the course of combat. Decisive points on today's fluid battleground are fleeting and often require hasty directives to secure favorable outcomes. Add to the frenetic pace of battle its increased geographic scope, and the ability of the commander to accurately assess the progress of combat and issue appropriate guidance is sorely tested. From a stationary ground station the task can become impossible. As a result, command and control is frequently exercised from a utility aircraft specifically configured with a command radio suite.

The flight mission is actually a mixture of two competing and contradictory tasks. Functionally, the aircraft must traverse large geographic areas with sufficient altitude to afford the commander a view of the battle and communications contact with his subordinates. Conversely, the crew must limit their exposure over the battlefield to minimize risk of destruction or capture. Consequently, the aerial command and control mission is inherently a precarious one.

d. Search and Rescue

Search and rescue entails the location and recovery of downed aviation crews. Although the Air Force/Air Component Commander is doctrinally charged with the responsibility for theater-level search and rescue, each service is required to maintain resources capable of performing the mission within their immediate operational area [Ref. 20: p. 2-19]. Search and rescue operations are distinguished by the areas in which they are performed. Missions confined to areas within friendly lines prompt overt combat rescue operations. Conversely, incursions into hostile territory generally require covert operations relying upon unique equipment and the capabilities of Special Forces personnel.

The selection of equipment and composition of rescue teams is dependent upon the survivors' condition, equipment available and the threat environment, permissive or nonpermissive. Crews routinely carry aeromedical personnel and specialized equipment used to extract personnel from terrain which precludes safely landing the aircraft. Additionally, unescorted search and rescue missions into enemy areas are normally performed at night using evasive flight techniques, terrain avoidance radar and night vision goggles [Ref. 20: p. 3-13]. An aviation unit's most valuable assets are its crews; despite the peril patently associated with the mission, the attempted recovery of a downed aircrew will usually be made.

e. Air Assault

Air Assault operations combine the lift and firepower capabilities inherent to the helicopter with those of dismounted infantry in a task organized team. Used principally to engage enemy forces or seize terrain, air assault assets afford the task force commander the unique ability to strike at the enemy throughout the breadth of the battle area largely unencumbered by extended distances and terrain irregularities. Both the aviation assets and the lifted forces are tactically tailored to the assigned mission. The infantry force is supplemented with other combined arms assets consistent with the demands of the assigned mission. Likewise, attack, observation, utility and cargo helicopters are incorporated into a self-supporting aviation team [Ref. 21: p. 1-1].

Characterized by deliberate planning and aggressive execution, air assaults manifest exceptional capabilities. By virtue of its heliborne mobility, the air assault can respond quickly to the rapid pace of combat operations. The force can engage an enemy from virtually any direction, thus achieving a degree of tactical surprise. Augmented by utility and cargo helicopters, such operations can be sustained independent of secure ground lines of communication for limited periods of time. Further, aviation reconnaissance assets provide the task force commander with immediate combat intelligence enabling him to effect necessary tactical adjustments as the operation proceeds. In short, the integration of helicopter and ground assault forces offers the most striking contemporary example of combat force synergism [Ref. 21: pp. 1-2-1-3].

V. THE AIRCRAFT

"Something like the helicopter comes along only rarely in history, every few hundred years."

LTG Harry W. O. Kinnard

Warfare today is a 'come as you are' proposition, and it exacts a heavy toll from combatants. The US cannot, as in the past, anticipate lengthy periods of mobilization to meet its military contingencies. Our current inventory of military equipment must be sufficient to meet our global contingency commitments; time to build another will be unavailable.

The responsibility of properly equipping the Armed Forces is a continuous and often thankless job. Because of inherent delays associated with converting a concept on paper into a piece of functional hardware, the problem must be approached in repetitive cycles. As one system is fielded another passes through concept analysis so that when the current systems exhaust their usefulness, timely replacement can occur. Often needs of the force must be projected twenty years into the future in order that advanced capabilities can be incorporated into follow-on weapon systems as they are needed.

This equipment renewal process is essential to the maintenance of combat effectiveness. As an armed force matures, its equipment naturally ages, periodically falls into disrepair and relative to newer additions to an opponent's weapons inventory, becomes less effective. Further, with age hardware accrues greater expense. The longer a system remains in service, the greater is its accumulation of wear, erosion and material fatigue and the greater is its chance for failure and subsequent repair. Also, procurement of replacement parts for older systems escalates maintenance costs as arms industries periodically retool to begin manufacture of newer systems and suspend support of older ones. Consequently, tactical and economic imperatives demand that more efficient equipment be regularly incorporated into the force.

Relative to Army Aviation, replacement and modification of aircraft is programmed and executed in accordance with a comprehensive procedure called the 'Army Aviation Modernization Plan.' The plan manages the Army's fleet of aircraft by reference to five distinct mission categories: attack, scout reconnaissance, utility, cargo and special electronic mission aircraft [Ref. 22: p. 37]. Airframes in each category are methodically overhauled, improved and eventually replaced in order to assure continuous evolution of the aircraft in consonance with the needs of the force and the advance of technology.

A portion of the plan published in May 1988 pertaining to utility aircraft outlined a typical expedient used to renovate the aging fleet. A large number of UH-1 Iroquois helicopters were to be eventually replaced by 2,253 of the newer UH-60 Black Hawk helicopters. Once the conversion was completed, the UH-60 would assume the majority of utility missions while the remaining balance of UH-1 aircraft would supplement the fleet performing aerial command and control, aeromedical evacuation and various rear area transport duties. Helicopters retired from the fleet would either be discarded or passed through a cursory maintenance upgrade preparatory to assignment to foreign military sales. Those remaining would enter a comprehensive overhaul program designed to upgrade their performance and capabilities to a level compatible with the newer UH-60. All of these plans were contingent upon sufficient contract funding being made available during each of the procurement years. More recent defense budget proposals indicate that such is not the case [Ref. 23].

Adjusting to an evaporating pool of defense dollars, the Army plans to suspend procurement of the Black Hawk helicopter beyond calendar year 1991. By that time total UH-60 procurement will have reached 1,147, considerably short of the 2,253 originally requested [Ref. 24]. The obvious alternative lies in retaining more UH-1 helicopters, the quantity of which will depend upon the actual number of UH-60s purchased and the results of Army force structure modifications. How this compromise translates into lost capability is best estimated through a technical comparison of the two aircraft.

The UH-1H Iroquois is a gas turbine driven helicopter currently in general use within the active, reserve and national guard forces. Built by Bell Helicopter Textron Inc. [Ref. 25: p. 341], the basic airframe has been modified numerous times to various mission configurations to include attack, aeromedical evacuation, electronic countermeasures and utility. The current utility aircraft version was first manufactured in September 1967, and today the active helicopter fleet contains 3,147 UH-1 helicopters in either the H (utility), M (gunship) or V (medevac) configuration [Ref. 26: p. 18].

The helicopter can carry a crew of two and eleven combat equipped soldiers or six litters with a medical attendant or 2,420 pounds of cargo [Ref. 27: p. 1-90]. Its range with maximum fuel is 318 statute miles [Ref. 25: p. 342] while its service ceiling is 24,210 feet [Ref. 27: p. 1-91].

Armed with two 7.62 mm machineguns, the aircraft can launch and recover from either hard surface or unprepared sites and perform its assigned mission during day, night, inclement weather or light icing conditions. Its two side sliding cargo doors and knee-level cargo floor permit rapid internal loading and unloading from either side while its 4,000 pound capacity cargo hook is used principally for transporting bulky external loads. Utility models can also be adapted with a variable speed hoist to accommodate tactical extractions [Ref. 27: p. 1-89].

Survivability features engineered into the standard utility design include a threat warning receiver, armored seats for the pilot and copilot and a crashworthy fuel cell which maintains its structural integrity during crash impact and will self-seal penetrations caused by projectiles no larger than 50 caliber. The aircraft's outer skin is painted with low reflectance paint, and some models carry an exhaust deflector designed to dissipate the engine's thermal signature in the induced rotor turbulence [Ref. 28].

Logistically, the UH-1 is described as an infinite life airframe because all of its component parts can be replaced thereby rendering them fatigue insensitive. This characteristic is not common to most aircraft. Normally, certain basic structural members cannot be replaced, and consequently, the aircraft assumes a limited useful life. Because the UH-1 is an exception to this rule, its cost of maintenance does not increase with age, a significant advantage. The helicopter enters a scheduled phase inspection each 150 flight hours and requires 280 manhours of support to restore it to full duty status [Ref. 29].

Originally the bulk of the UH-1 fleet was scheduled to be replaced on a two-for-one exchange by the newer UH-60. Those retained by the Army would enter a service life extension program to provide them capabilities comparable to the remainder of the rotary-winged fleet. Planned material improvements included an update of navigation and communication equipment, provision of infrared suppression, chaff and flare dispensers and installation of new composite construction rotor blades [Ref. 25: p. 341].

The UH-60A Black Hawk was originally designed as a tactical troop carrier to replace the UH-1. In Vietnam, helicopter performance suffered as a result of deficiencies concerning lift capability, crash survivability, ballistic and infrared missile protection. Accordingly, remedial measures were incorporated into specifications for the next generation utility aircraft. The winning design, built by Sikorsky, was capable of transporting an entire eleven man squad and its complement of equipment [Ref. 30: p. 11]. The first Black Hawk officially entered active service in October 1978 with a forecast useful life of 30 years, and today the equipment inventory totals 1,036 aircraft [Ref. 24]. The aircraft is driven by two turboshaft engines and is armed with two 7.62 mm machineguns. Like its predecessor, the UH-60 can adapt to the aeromedical role (carrying six standard litters and an attendant) as well as cargo and passenger transport. The aircraft enters a major scheduled service each 500 flight hours and typically requires 700 manhours of maintenance support to be restored to a mission ready status [Ref. 31].

Its survivability is enhanced by infrared suppression, chaff and flair dispensers, threat radar warning, an electronic jammer and composite rotor blades. Its light alloy construction is designed to withstand vertical, lateral and longitudinal crashes of 38, 30 and 40 ft/sec, respectively. With external fuel tanks the helicopter's range is extended from 373 statute miles to 1380 miles affording it self-deployment capability [Ref. 25: pp. 480-1]. Through a combination of selective armor plating, composite construction and redundant components, the aircraft can sustain penetration by projectiles of up to 23 mm without mission interruption [Ref. 32]. In short, its design performance specifications meet or exceed those of the UH-1.

Salient features of the two aircraft are summarized in Table 2.

Table 2. AIRCRAFT COMPARISON

Attributes	UH-1	UH-60
Maximum Range	124 nm	133 nm
Passenger Capacity	11	15
Cargo Capacity (lbs)	2,420	3,360

Technically, the UH-60 is the superior aircraft. Considering the fact that its design was specifically formulated to overcome deficiencies found in the UH-1, this conclusion is not surprising. The Black Hawk statistics demonstrate a clear advantage over the older Iroquois in payload, infrared suppression, ballistic tolerance and crash survivability. Conversely, the Black Hawk is more expensive to procure as well as repair. In light of a radically evolving security environment and a constrained defense budget, the original question concerning UH-1 helicopter retention remains unanswered. For though the Army might simply decide to discard less of the older airframes to accommodate unsupported mission requirements, it has yet to determine which aircraft is more capable with regard to future commitments. Can the Army afford to operate the more technically advanced aircraft from a stringently limited budget? If future Army intervention occurs in LIC, it must anticipate a lengthy involvement without America's transition to a war footing. And further, is the performance of the Black Hawk helicopter which is primarily designed for mechanized warfare, actually superior to the Iroquois in a LIC setting? The Army has often been accused of buying oversophisticated equipment and ultimately getting "less and less bang while U. S. defense contractors got more and more bucks." [Ref. 33: p. 617]

That these questions can be asked before the helicopter inventory is irrevocably depleted and while the threat evolves is indeed fortuitous. Still, answers to these questions cannot be deduced by a simple table comparisons; however they can be generated using contemporary statistical analysis.

VI. THE MODEL

"She had not understood mathematics until he had explained to her that it was the symbolic language of relationships. 'And relationships,' he told her, 'contained the essential meaning of life.'"

Pearl S. Buck

As stated previously, the intent of this thesis is to determine which of two aircraft is superior in the LIC environment. The comparison will be made using a semi-Markov process to model aircraft operation and generate appropriate measures of performance. The rationale for selecting the semi-Markov process and a description of its formulation offer insight regarding the accuracy of its conclusions.

Use of mathematical models to replicate functional aspects of real systems and record their performance is a popular tool among analysts. Running a model usually obviates the need to exercise the actual system, substantially reducing the accompanying expense. In some situations, because of the perishable nature of the subject or the fact that the item of interest resides entirely in a conceptual form, modeling provides the only plausible analytical medium. Military combat falls within this latter category, and as a consequence, military planners rely heavily upon models to predict behavior of weapon systems and assess their capabilities.

Combat models in the past have taken one of two distinct forms: high resolution models attempting to depict individual combatants and aggregated models which represent forces as groups. Both require generous amounts of technical support for initial formulation as well as the tactical trials that follow. Alterations of the initial scenario are, likewise, labor intensive which tends to discourage use of either model type for wholesale sensitivity analysis. As a result of the extensive effort required to build and modify such models, contemporary military modeling projects frequently employ small inexpensive models which can be built quickly, easily manipulated and ultimately discarded. By concentrating upon specific combatants or aspects of combat, such models escape the minutiae attached to peripheral elements.

Though small, adaptive models hold obvious appeal, their use, nonetheless, must be tempered with caution. The model, to include its assumptions, must accurately complement the subject and objectives of the study. Levels of abstraction, requirements for sensitivity analysis and use of underlying probability distributions must be considered in their selection, or otherwise, results may be misleading and erroneous.

With specific reference to the analysis of this thesis, the model must forecast without bias, the performance of two, technically dissimilar aircraft. Americans traditionally admire technological sophistication, in many instances believing it to be their prime advantage militarily as well as economically over opponents. In a nation predisposed to 'high tech' solutions, technical impartiality will not be easy to achieve. Also, the model must consider the aircraft in the low intensity conflict (LIC) regime.

LIC is not peculiar to a particular geographic location; rather it is a style of warfare which includes a variety of operational environs. In other words, LIC is equally applicable in the triple canopy jungles of Southeast Asia, the mountains of Afghanistan or the deserts of Iran. Each environment is characterized by unique weather, temperatures, altitudes and terrain all of which the model must evaluate to perform a valid comparison. Aircraft unsuitability to a particular regime must be discovered before it can jeopardize an assigned mission. The commander of the hostage rescue attempt, Desert One, aborted his operation because the attached helicopters developed mechanical problems caused by desert sand and dust, an embarrassing oversight for a nation which prides itself on technological advantage.

Further, the proliferation of infrared detection devices and similarly equipped weapon systems among modern insurgent forces underscores the Army's need to perform missions without regard for the time of day. Consequently, potential helicopter limitations associated with day and night operations must be identified and incorporated into the comparison. In sum, the model must distinguish between two main variables: time of day and environment, and register sufficient information to accurately and impartially evaluate aircraft effectiveness.

The selection of variables of interest leads logically to choice of an appropriate analytic model. At first glance, high resolution simulation provides a legitimate approach. It replicates the operational environment, records results efficiently and incorporates chance outcomes into the battle's play through stochastic algorithms. However, as noted previously, the excessive labor involved with such projects favors employing more economic alternatives such as the semi-Markov process.

Possibly the strongest argument supporting use of a semi-Markov process is speed. The model quickly generates solutions to a stochastic problem in terms of expected values. Though formulation of the model can absorb considerable effort, especially when the desired level of detail is minute, once the model's matrices have been assembled, performance measures can be calculated in seconds.

Consistent with the model's speed is its transparency. Input parameters can be modified separately or in combinations with relative ease, and the effects of modifications are manifest immediately. Thus, sensitivity analysis is easily accomplished using this technique. Another benefit regards level of detail. The refinement of the model is controlled entirely by the analyst. Should the analyst need more specific information, he/she can amend a portion of the model while leaving the remainder unaltered or can increase the detail of the entire formulation. And finally, the technique is extremely versatile in that an initial analysis can serve as a paradigm for similar hardware comparisons. For example, variations of this model could have been used to select a cockpit configuration from competing designs for the V-22, tilt-rotor aircraft, or to choose between contractor prototypes preparatory to a contract award decision for the LHX.

Despite the inherent advantages of the semi-Markov process, its selection to assess helicopter performance is ultimately contingent upon satisfying the model's basic assumptions described in the following definition:

> "A semi-Markov process is one that changes states in accordance with a Markov chain but takes a random amount of time between changes. More specifically consider a stochastic process with states 0, 1, ..., which is such that, whenever it enters state i, $i \geq 0$:
>
> (i) The next state it will enter is state j with probability P_{ij}, $i,j \geq 0$.
>
> (ii) Given that the next state to be entered is state j, the time until the transition from i to j occurs has distribution F_{ij}.
>
> If we let $Z(t)$ denote the state at time t, then $\{Z(t), t \geq 0\}$ is called a semi-Markov process." [Ref. 34: p. 130]

At the heart of the semi-Markov process is a discrete time Markov chain. A Markov chain is a stochastic process which consists of a finite number of values or states and passes from state to state subject to fixed probabilities. The chain is characterized by the Markovian property which states that the transition probabilities from the present state are independent of the past [Ref. 34: p. 100]. By convention, the fixed transition probabilities are usually represented in matrix notation where individual elements, P_{ij}, denote the probability of passing from state i to state j. The following example shows such a matrix defined by three states, {1, 2, 3}.

$$P = \begin{vmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{vmatrix}$$

Likewise, a helicopter flight can be described by various finite sequences of mutually exclusive states. A typical aircraft mission is composed of several segments, some of which occur always and others, occasionally. Each of these mission segments can be described as a unique state which the aircraft enters, occupies for a period of time and possibly exits. Linking segments in appropriate sequences 'builds' an aircraft mission.

To illustrate, all missions begin with a *takeoff maneuver*. Once the takeoff is completed, the pilot transitions into forward flight en route to his predetermined destination. From forward flight he might land and pick up passengers, develop mechanical difficulties which force him to cancel the mission, or be shot down by enemy forces. Each of these possibilities describes a state which the pilot could enter from forward flight. Associated with each of these conditions is a fixed probability estimating the chance that the aircraft will advance from forward flight to that subsequent state. In this way, probabilities are used to represent spontaneous (i.e. *hostile enemy fire*) as well as rehearsed (i.e. evasive maneuver) events. Because the number of conceivable mission segments is finite, they can be consolidated into a discrete time Markov chain.

The other major component of the semi-Markov process regards the time a state remains occupied, typically called sojourn time. Associated with each transition is a particular time distribution which for helicopter flights can be represented by constant time durations drawn from actual flight experience. Continuing the example, the amount of time that pilots spend flying prior to loading passengers, being shot down or developing mechanical difficulties can be estimated and tabulated into a transition time matrix which, when paired with the discrete time Markov chain, defines a semi-Markov process.

With the model's conceptional justification accomplished, the state space used in this analysis was formulated based upon the flight missions previously enumerated. Each of the five standard utility helicopter missions was divided into mutually exclusive segments which were combined to form rows and columns of a transition matrix. An identical matrix was built for each of three environments (jungle, mountain and desert), two lighting conditions (day and night), and two helicopter types (UH-1 and UH-60). With the assistance of experienced pilots from Fort Ord and Fort Rucker, transition probabilities and sojourn times were entered into the twelve matrices. Through algebraic manipulation each transition probability/time matrix pair generated measures of performance peculiar to a specific environment, lighting condition and aircraft.

The flight segments composing the state space were intentionally selected to represent variables of interest to the analysis. Though all portions of a hypothetical mission profile must appear in some form within the state space array, those events upon which measures of effectiveness (MOE) depend were depicted by unique states.

For example, the forecast number of 'successful launches', 'accidents' and 'cargo deliveries' were essential components of the primary MOE and were consequently reflected by separate states. Conversely, 'evasive maneuvers', 'hovering' and 'returning fire' were actions noncritical to this analysis and were, as a result, absorbed within more comprehensive states such as 'performing terrain flight navigation' or 'preparing an external load operation'.

A complete listing and explanation of the states chosen to characterize utility helicopter flight missions are provided in Appendix B. The computer program written in A Programming Language (APL) and used to algebraically manipulate the matrix pairs and generate MOE is listed in Appendix C while a simple example illustrating the computational methodology is included in Appendix D.

VII. THE ANALYSIS

"New conditions require for solution, and new weapons require for maximum application, new and imaginative methods."

General Douglas MacArthur

How does one best approach a comparison of two dissimilar aircraft bound to a common mission? What factors are relevant to contemporary military leaders and can best assist them in making informed decisions regarding our future force structure? Of fundamental importance is operational effectiveness. Doctrinally, this concept hinges upon two factors: mission performance and survivability [Ref. 35: p. 2-2]. Accordingly, these same two elements were used to guide selection of various measures of effectiveness (MOE) with which to compare the two aircraft. Further, with the future expectation of smaller defense budgets, contemporary military planners must better appreciate the costs associated with active inventory hardware. Therefore, a cost analysis supplementing the performance measures was included to specifically address the expense issue. Hopefully, these factors presented in concert should sufficiently quantify functional and fiscal differences between the two aircraft to accomplish a valid comparison.

The approach used in this analysis generally follows a deductive argument leading to basic conclusions relative to each aircraft. Initially, limiting assumptions were made to pare the comparison to a manageable size. Concurrent with formulation of the model's state space, MOE were selected to characterize the cost and performance factors. Next, three hypothetical situations were constructed, two reflecting bias toward one or the other aircraft and a third representing a compromise between the two extremes. Finally, using MOE generated from the three situations, differences in performance and costs associated with the two helicopters were compared and analyzed. A more thorough review of this process substantiates not only the validity of the conclusions but also the utility of the model.

In addition to specific mathematical assumptions previously enumerated regarding selection of the semi-Markov process, other basic assumptions were used to facilitate the analysis. In order to avoid the myriad questions regarding tactics and aircraft mixes, single aircraft were compared. Consequently, the synergistic effects possible by organizing aircraft in various combinations were considered equivalent for both aircraft types and effectively ignored.

Relative to formulation of the model's transition matrices, input probabilities and sojourn times were ultimately based upon the opinions of one individual, the author, using his experience, technical research and discussion with other military aviators. Although different pilots might disagree with the values chosen, hopefully, they would agree with the general trend of values proposed between aircraft and between scenarios. To illustrate, the transition probability matrices portray the UH-60 generating a smaller signature than its predecessor while enjoying superior ballistic tolerance to enemy fire. Furthermore, though human error and mechanical malfunction contribute to aircraft accidents, in hostile environments the risk associated with aircraft destruction is primarily associated with enemy fire. Because a helicopter's flight profile is more exposed in desert areas, less in jungles and fairly obscured in mountainous regions, threat effectiveness against both aircraft is characterized greatest in the desert and progressively less in jungles and mountains. Likewise, risk of engagement is reflected greater during daylight conditions than at night. Therefore, because the analysis will involve comparative trends between the helicopters as much as specific values, disagreements concerning specific index values should not invalidate the conclusions.

To adequately characterize aircraft operation, eight separate MOE were used in various combinations. Functionally, the eight performance measures separate into one of two categories, mission accomplishment and aircraft performance. Because both aircraft are primarily used as means of transport, the average daily delivery capabilities in terms of cargo weight (MOE 1) and personnel (MOE 2) were used to assess mission accomplishment while the remaining six measures emphasize qualities associated with aircraft performance. MOE 3, the expected aircraft lifetime, gives a broad initial estimate of aircraft survivability. Narrowing that estimate to the time an aircraft spends in an operationally ready status, MOE 4 predicts the expected aircraft useful lifetime while MOE 5, the difference between MOE 3 and 4, represents the time absorbed in maintenance and repair. MOE 6, the average hourly flight mission length, gauges the model's inherent realism. Agreement between predicted mission lengths and aircraft flight endurance times provides a degree of model verification, lending credibility to the model's forecasts. MOE 7, the number of successful aircraft launches, offers yet another indication of aircraft longevity while the last performance measure, MOE 8, represents the percent of an aircraft's expected lifetime spent flying missions. Table 3 summarizes the calculations associated with each MOE.

Table 3. MEASURES OF PERFORMANCE CALCULATIONS

MOE 1	MOE7*Max Acft Cgo Load/MOE3
MOE 2	MOE7*Max Acft Pass Load/MOE3
MOE 3	Algebraic Manipulation of Input Matrices
MOE 4	Algebraic Manipulation of Input Matrices
MOE 5	MOE3-MOE4
MOE 6	Algebraic Manipulation of Input Matrices
MOE 7	Algebraic Manipulation of Input Matrices
MOE 8	MOE6*MOE7/MOE3

Those entries which indicate calculation by means of algebraic manipulation involve operations upon the input transition matrices. Because their calculation is quite complicated, the interested reader should consult the algorithm listed in Appendix C.

The first of three hypothetical situations, serving as the base case, contained probabilities representing actual aircraft capabilities. Consistent with the previously described trends, the UH-60 enjoyed greater tolerance to enemy fire as indicated by probabilities associated with aircraft damage assessment. Conversely, a damaged UH-60 was more inclined to require extensive repair effort than the UH-1. Tables 4 and 5 summarize the salient probabilistic differences between the two aircraft relative to the initial situation.

Table 4. PROBABILITY OF LANDING UNDAMAGED/DAMAGED

Acft	Day			Night		
	Desert	Jungle	Mount	Desert	Jungle	Mount
UH-1	.80/.20	.85/.15	.87/.13	.85/.15	.88/.12	.92/.08
UH-60	.87/.13	.89/.11	.92/.08	.90/.10	.92/.08	.95/.05

Table 5. PROBABILITY DAMAGE IS MODERATE/SEVERE

Acft	All Environs
UH-1	.90/.10
UH-60	.86/.14

Measures associated with mission performance relative to the first set of conditions demonstrate some surprising results which are tabulated in Table 6.

Table 6. MEASURES OF PERFORMANCE #1 AND #2

MOE	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
Max Cargo Delivered Daily	UH-1	1279.0	1369.6	1395.7	1345.1	1409.0	1494.4
	UH-60	1261.1	1304.1	1388.6	1309.3	1365.1	1452.1
Max Passengers Delivered Daily	UH-1	5.8	6.2	6.3	6.1	6.4	6.8
	UH-60	5.6	5.8	6.2	5.8	6.1	6.5

Assuming each aircraft is dedicated to cargo or passenger transport, each of the listed scenarios postulates that the UH-1 will deliver greater quantities of men or equipment daily than its planned replacement, the UH-60. Admittedly, the surplus is only marginal, varying from 0.5% in the Day Mountain setting to 5% in Day Jungle conditions; but even the presumption that the two are comparable is startling. The rationale for this apparent disparity stems from the inordinate amount of time needed to repair and maintain the more technically sophisticated UH-60. Though the aircraft enters a major preventive maintenance service once each 500 hours, the amount of labor involved in the service approaches 700 manhours. Conversely, the UH-1 enters service more frequently, at 150 hour intervals, but requires only 280 manhours to return to operational status [Ref. 31]. Similarly, the amount of labor associated with combat damage repair is greater for the UH-60.

Discounting performance differences between aircraft, the trends apparent throughout the range of scenarios are consistent with the fundamental assumptions regarding risk. As danger associated with the enemy increases from mountain to jungle to desert settings and from night to day conditions, one would expect deliveries of cargo and men to decline, and indeed they do.

Considered collectively, MOE 3 through 5 provide a broad estimate of aircraft survivability. Forecast values are presented in Table 7.

Table 7. MEASURES OF PERFORMANCE #3, #4 AND #5

MOE	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
Total Acft Life (days)	UH-1	154.3	233.5	480.1	204.7	352.2	473.4
	UH-60	637.9	1475.5	1989.8	953.0	1399.3	1924.7
Acft Useful Life (days)	UH-1	93.8	152.1	322.6	134.2	240.7	344.8
	UH-60	272.1	649.5	925.5	429.3	652.3	954.4
Acft Main/Repair Time (days)	UH-1	60.5	81.4	157.5	70.5	111.5	128.7
	UH-60	365.8	826.0	1064.2	523.7	747.0	970.3

The data confirm that in all environments the UH-60 is a more survivable aircraft. Useful lifetime figures (MOE 4) indicate that the UH-60 will outlive the UH-1 by from 170% in the Night Jungle scenario to 327% in the Day Jungle setting or averaged over all scenarios, 201%. However, this added longevity is not gratuitous. The associated cost is identified in the excessive time spent in maintenance and repair (MOE 5). The time spent in nonoperational status by the UH-60 is from six to ten times that of the UH-1, and of its expected total lifetime, 50% to 57% can be anticipated in an other-than-useful condition. Not only does this relatively high percentage of maintenance detract from the aircraft's flight mission, but it suggests that use of the UH-60 must be accompanied by a larger, more extensive support organization.

The last three MOE provide supplemental information used to verify consistency between previous performance measures as well as empirical performance data. Values are indicated in Table 8.

Table 8. MEASURES OF PERFORMANCE #6, #7 AND #8

MOE	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
Avg Msn Length (hours)	UH-1	1.8	1.7	1.8	2.2	2.0	2.0
	UH-60	1.5	1.3	1.1	1.5	1.2	1.2
Number of Mission Launches	UH-1	81.6	132.1	276.9	113.8	205.1	292.4
	UH-60	239.4	572.7	822.3	371.4	568.5	831.8
Flight As a Percent Acft Life	UH-1	.040	.040	.043	.051	.048	.052
	UH-60	.024	.020	.019	.024	.021	.022

The average duration of a flight mission provides the primary linkage between the model's predictions and historical data. Notice that relative to the UH-1, data values do not exceed its maximum flight endurance of 2.5 hours [Ref. 28]. Similarly, the UH-60's maximum forecast mission duration of 1.5 hours is well below its flight endurance of 2.3 hours [Ref. 32]. Also, the consistently shorter times logged by the UH-60 are indicative of its faster cruise speed, 120 knots as compared to 90 knots for the UH-1.

The count of successful mission launches (MOE 7) offers another measure of longevity and provides a check of consistency against the useful lifetime of the aircraft. Broadly speaking, the measure represents the number of successful missions one can anticipate throughout the aircraft's life. Theoretically, differences separating aircraft relative to mission launches should closely parallel corresponding differences in the number of useful days available (MOE 4). A quick calculation confirms that the respective differences vary by no more than 4%. The number of days by which launches lag useful days results from a 24 hour interval with which the model interspaces all missions.

The final performance measure, flightime as a percentage of aircraft lifetime (MOE 8), provides another perspective of aircraft performance. That the numbers are small must be expected; the combination of necessary repairs, maintenance, crew availability and general idleness would tend to absorb considerable time driving the measures down. The revealing aspect of these values is the degree by which the less sophisticated UH-1 exceeds the UH-60, on the average 110%. As noted previously, the difference is attributable to maintenance and repair demands of the UH-60. But the regularity and magnitude of advantage enjoyed by the UH-1 suggests a direct correlation between higher technology and reduced availability.

The second and third situational variations were created to investigate effects resulting as a consequence of adjusting transition probabilities to favor one aircraft or the other. This portion of the analysis demonstrates the model's transparency and hence its ability to perform sensitivity analysis. Though each of these 'extreme' situations reflects bias toward a specific helicopter, the assigned probabilities were not unrealistic as a description of the first variation confirms.

In order to create controlled bias favoring the UH-1, probabilities associated with that aircraft were held constant while data elements associated with the UH-60 were altered. First, the UH-60's tolerance to enemy fire was reduced 1% to 2%, though not below that of the UH-1. Second, the UH-60's requirement for extensive repair effort as a result of battle damage was increased 6%. The probability adjustments are summarized in Tables 9 and 10.

Table 9. PROBABILITY OF LANDING UNDAMAGED/DAMAGED (BIAS UH-1)

Acft	Day			Night		
	Desert	Jungle	Mount	Desert	Jungle	Mount
UH-1	.80/.20	.85/.15	.87/.13	.85/.15	.88/.12	.92/.08
UH-60	.85/.15	.87/.13	.90/.10	.88/.12	.91/.09	.94/.06

Table 10. PROBABILITY DAMAGE IS MODERATE/SEVERE (BIAS UH-1)

Acft	All Scenarios
UH-1	.90/.10
UH-60	.80/.20

Though similar changes are manifest proportionally throughout many of the indices, the effect is clearly seen by reference to daily cargo deliveries (MOE 1) alone as shown in Table 11.

Table 11. MEASURE OF PERFORMANCE #1

MOE	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
Max Cargo Delivered Daily	UH-1	1279.0	1369.6	1395.7	1345.1	1409.0	1494.4
	UH-60	1159.7	1203.1	1288.3	1210.4	1295.2	1389.1

As cursory examination indicates, pounds of cargo delivered daily by the UH-60 have decreased relative to each scenario. Where before the UH-1 enjoyed a very marginal advantage, now the gap separating the two aircraft has widened to between 7.5% to 13.8%, a substantial rise. Earlier findings would suggest that though the reduction of ballistic protection would account for a modest share of the growth, the majority resulted from the UH-60's severe time penalty associated with extensive repair operations.

Table 12. PROBABILITY OF LANDING UNDAMAGED/DAMAGED (BIAS UH-60)

Acft	Day			Night		
	Desert	Jungle	Mount	Desert	Jungle	Mount
UH-1	.80/.20	.85/.15	.87/.13	.85/.15	.88/.12	.92/.08
UH-60	.90/.10	.92/.08	.95/.05	.91/.09	.94/.06	.97/.03

Table 13. PROBABILITY DAMAGE IS MODERATE/SEVERE (BIAS UH-60)

Acft	All Environs
UH-1	.90/.10
UH-60	.90/.10

As Tables 12 and 13 indicate, the second situational variation with bias favoring the UH-60, was prepared with probabilistic adjustments analogous to the previous trial save in the opposite direction. Probabilities associated with the UH-60's ballistic resistance increased 2% to 3% while those relating to damage repair were equated with the UH-1's.

Table 14. MEASURE OF PERFORMANCE #1

MOE	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
Max Cargo Delivered Daily	UH-1	1279.0	1369.6	1395.7	1345.1	1409.0	1494.4
	UH-60	1366.3	1410.5	1497.2	1365.0	1444.6	1529.2

The amount of daily cargo delivered by the UH-60, reflected in Table 14, now shows a significant increase over measures recorded for the preceding two trials. In this instance a reversal has occurred as the UH-60 now enjoys complete dominance over the UH-1 relative to this performance measure ranging from 1.5% in the Night Desert setting to over 7% in the Day Mountain environment.

Having examined eight separate measures of effectiveness and two excursions involved with damage accrual and repair, the comparison lacks an analysis of cost. Aircraft expenditures can be broadly grouped into three categories: procurement, repair and maintenance. Because this study concerns use and disposition of existing hardware assets, procurement costs are irrelevant and, accordingly, are ignored. The US Army Safety Center located at Fort Rucker, Alabama, collects and records data pertaining to accidents involving Army aircraft by fiscal year. Within their computer archives are stored detailed information regarding each accident to include costs associated with material loss and repair. Also located at Fort Rucker, the US Army Aviation Center administers flight training and qualification for the Army's pilots and, consequently, maintains a fleet of fixed and rotary-winged aircraft. In addition to accident information requested from the Safety Center, estimates of labor costs associated with periodic maintenance of the UH-1 and UH-60 were requested from a representative of the local contracting office. Table 15 tabulates relevant cost figures in dollars.

Table 15. COST PARAMETERS

	UH-1	UH-60
Organizational Maintenance	0	122
Intermediate Maintenance	4,200	24,500
Avg Accident Cost	1,800.33	5,603.17

Rather than simply comparing operating costs among aircraft, pounds of delivered cargo were selected as a common reference with which to relate costs to performance. Accordingly, a cost ratio taking the form of the delivery cost of a pound of cargo, was used to evaluate the two helicopters, both assumed dedicated exclusively to the cargo mission. The resulting cost ratios based upon the initial probability data set (base case) are presented in Table 16.

Table 16. COST EFFECTIVENESS RATIOS

	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
$ per Pound Delivered	UH-1	.25	.20	.18	.20	.17	.14
	UH-60	.50	.44	.35	.42	.36	.27

The cost ratios which are notably independent of time, generally parallel results associated with the daily cargo delivery rate (MOE 1). In all cases the UH-1 proves the more economic alternative by a considerable margin (204% averaged across all scenarios). The trends reflected in the cost ratios also parallel those of the daily cargo delivery rate as both aircraft encounter cost increases as the mission passes from mountains through jungles to deserts and likewise from night to daylight operations. In sum, while the daily cargo delivery rate revealed a relatively expensive penalty in terms of repair and maintenance time associated with the UH-60, the cost ratios reflect a similar penalty in terms of dollars; analytical evidence that time is indeed money.

VIII. A SUMMARY OF FINDINGS

"New opinions are always suspected, and usually opposed, without any other reason but because they are not already common."

Locke

It would be inappropriate for an analyst to declare absolutely one aircraft superior to another regardless of his results. The semi-Markov process used to model aircraft performance was largely based upon the opinions of a single pilot. Also, the performance measures and cost ratios selected to facilitate the comparison, admittedly, could not evaluate all aspects of aircraft operation. And yet as a preliminary analysis, certain findings should be of considerable value to planners contemplating the composition of the Army's future utility helicopter fleet.

Operational effectiveness categorized in terms of its two doctrinal components, mission performance and aircraft survivability, provided the initial focus of the analysis. Regarding daily mission performance, the UH-1 marginally surpassed the UH-60's capability to deliver cargo and personnel to destination *in all operational environments* considered. This result is directly attributable to the lengthy periods of time required by the UH-60 for maintenance and repair. Conversely, the UH-60 has greater longevity by a substantial margin in all operational settings.

Regarding aircraft operation costs, expenses associated with the UH-60 generally exceed those of the UH-1 by 200%. This cost analysis should assume greater relevance when considered in light of potentially long term low intensity conflicts coincident with diminished defense budgets.

Also, the greater logistical dependence forecast for the UH-60 will likely require a larger, more extensive maintenance organization and may require greater numbers in units to insure the availability of continuous support.

As a preliminary report, this analysis has revealed some surprising relationships between two dissimilar utility helicopters. The analysis has also demonstrated the ease and power associated with the semi-Markov process as a forecasting modeling tool. What remains is a rigorous verification of the model's input parameters and, subject to the questions of Army leadership, appropriate modification and/or expansion of the model.

In this way the comparative strengths and weaknesses of the subject aircraft will be made apparent and future decisions regarding procurement and retention will be made wisely.

APPENDIX A. PROBABILITY AND TIME TRANSITION MATRICES

Table 17. UH-1 TRANSITION PROBABILITY MATRIX (DAY DESERT)

	initial T O	tac T O	tac nav	search	ID LZ	loiter	land en route	load cgo cas	sling ext load	rappeling opn	paradrop	unload	refuel rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T O			.93												.02	.05											
tac T O			.93												.02	.05											
tac nav				.05	.39		.02							.02	.01	.07	.15				.01		.28				
search					.53									.02	.01		.44										
ID LZ						.45	.32			.04	.03						.08					.08					
loiter							.95				.05																
land en route		.02						.3	.1			.5	.06						.02								
load cgo cas		.98																	.02								
sling ext load	.1	.88																	.02								
rappeling opn			.98																.02								
paradrop			.5													.4	.05		.05								
unload		.43						.1					.05						.02				.4				
refuel rearm		.8						.2																			
lost			.2	.65			.02									.05	.08										
VHIRP														.01		.87	.1				.02						
500 AGL			.1	.02	.25										.01		.1		.05				.47				
detected			.52	.08															.4								
land OK																								.03		.97	
engaged		.3	.4					.15				.09									.02						.04
land damaged																								.1	.9		
drop ext load		.35	.45																.2								
land ext load		.3						.05				.25	.07										.33				
land EOM																		.8		.2							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 18. UH-1 TRANSITION TIME MATRIX (DAY DESERT)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T O			.1												.1	.1											
tac T O			.1												.1	.1											
tac nav				.2	.4		.1							.3	.3	.2	.2				.3		.4				
search					.3									.3	.3		.2										
ID LZ						.1	.1			1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.2			.1	.1						.1								
load cgo cas		.2																	.1								
sling ext load	.1	.1																	.1								
rappeling opn			.1																.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1			.1									.1	.1										
VHIRP														.1		.2	.1				.1						
500 AGL			.2	.1	.1										.2		.1		.1				.2				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										168	
shop																								24		48	
await msn	24								24																		
destroyed																											

Table 19. UH-1 TRANSITION PROBABILITY MATRIX (DAY JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.88												.02	.1											
tac T/O			.89												.01	.1											
tac nav				.05	.45		.02							.02	.01	.03	.1				.02		.3				
search					.57									.02	.01		.4										
ID LZ						.5	.25			.08	.02						.06					.09					
loiter							.95				.05																
land en route		.02						.25	.1			.49	.05			.02			.07								
load cgo/cas		.97																	.03								
sling ext load	.1	.87																	.03								
rappeling opn			.97																.03								
paradrop			.2													.69	.05		.06								
unload		.43						.1					.05						.03				.39				
refuel/rearm		.8						.2																			
lost			.3	.54			.01								.01	.1	.04										
VHIRP														.01		.93	.05				.01						
500 AGL			.05	.02	.2										.01		.05		.05				.62				
detected			.56	.09															.35								
land OK																								.03		.97	
engaged		.29	.38					.15				.13									.02						.03
land damaged																								.1	.9		
drop ext load		.4	.45																.15								
land ext load		.27						.05				.3	.08										.3				
land EOM																		.85		.15							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 20. UH-1 TRANSITION TIME MATRIX (DAY JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T O			.1												.1	.1											
tac T O			.1												.1	.1											
tac nav				.2	.4		.1							.3	.3	.2	.2				.3		.4				
search					.3									.3	.3		.2										
ID LZ						.1	.1			1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.2			.1	.1			.1			.1								
load cgo cas		.2																	.1								
sling ext load	.1	.1																	.1								
rappeling opn			.1																.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1			.1								.1	.1	.1										
VHIRP														.1		.2	.1				.1						
500 AGL			.2	.1	.1										.2		.1		.1				.2				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										168	
shop																								24		48	
await msn	24								24																		
destroyed																											

Table 21. UH-1 TRANSITION PROBABILITY MATRIX (DAY MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T O			.83												.02	.15											
tac T O			.85													.15											
tac nav				.05	.44		.02							.01	.01	.06	.08				.03		.3				
search					.63									.01	.01		.35										
ID LZ						.48	.3			.06	.01						.03					.12					
loiter							.95				.05																
land en route		.02						.18	.05			.6	.04			.07			.04								
load cgo cas		.97																	.03								
sling ext load	.1	.87																	.03								
rappeling opn			.87													.1			.03								
paradrop			.1													.82	.03		.05								
unload		.49						.05					.02						.03				.41				
refuel rearm		.8						.2																			
lost			.35	.4											.01	.2	.04										
VHIRP														.01		.91	.05				.03						
500 AGL			.05	.2	.2										.01		.05		.03				.46				
detected			.6	.1															.3								
land OK																								.03		.97	
engaged		.24	.37					.2				.15									.02						.02
land damaged																								.1	.9		
drop ext load		.35	.5																.15								
land ext load		.32						.05				.2	.03										.4				
land EOM																		.87		.13							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 22. UH-1 TRANSITION TIME MATRIX (DAY MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1													.1											
tac nav				.3	.5		.1							.3	.3	.2	.3				.3		.5				
search					.4									.3	.2		.4										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.2			.1	.1			.1			.1								
load cgo/cas		.2																	.2								
sling ext load	.1	.1																	.1								
rappeling opn			.1													.1			.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1											.1	.1	.1										
VHIRP														.1		.2	.1				.1						
500 AGL			.2	.1	.2										.1		.2		.2				.3				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										168	
shop																								24		48	
await msn	24								24																		
destroyed																											

Table 23. UH-1 TRANSITION PROBABILITY MATRIX (NIGHT DESERT)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.88												.02	.1											
tac T/O			.88												.02	.1											
tac nav				.09	.35		.02							.02	.01	.1	.15				.01		.25				
search					.68									.01	.01		.3										
ID LZ						.5	.25			.02	.07						.08					.08					
loiter							.95				.05																
land en route		.02						.3	.05			.5	.03			.05			.05								
load cgo cas		.97																	.03								
sling ext load	.08	.87																	.05								
rappeling opn			.99																.01								
paradrop			.6													.35	.01		.04								
unload		.43						.1					.02						.05				.4				
refuel rearm		.85						.15																			
lost			.2	.5			.05									.15	.1										
VHIRP														.02		.85	.1				.03						
500 AGL			.12		.3										.01		.1		.05				.42				
detected			.4	.1															.5								
land OK																								.03		.97	
engaged		.3	.4					.15				.11									.02						.02
land damaged																								.1	.9		
drop ext load		.35	.5																.15								
land ext load		.33						.05				.2	.05										.37				
land EOM																		.85		.15							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 24. UH-1 TRANSITION TIME MATRIX (NIGHT DESERT)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1												.1	.1											
tac nav				.3	.5		.1							.3	.3	.4	.2				.3		.5				
search					.3									.2	.2		.3										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.2			.1	.1			.1			.1								
load cgo cas		.3																	.1								
sling ext load	.2	.2																	.1								
rappeling opn			.1																.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1			.1									.1	.1										
VHIRP	.													.1		.2	.1				.1						
500 AGL			.3		.3										.2		.2		.2				.4				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										168	
shop																								24		48	
await msn	24								24																		
destroyed																											

Table 25. UH-1 TRANSITION PROBABILITY MATRIX (NIGHT JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.83												.02	.15											
tac T/O			.85													.15											
tac nav				.05	.45		.02							.02	.01	.08	.05				.02		.3				
search					.73									.01	.01		.25										
ID LZ						.5	.28			.04	.04						.05					.09					
loiter							.95				.05																
land en route		.02						.26	.05			.51	.03			.05			.08								
load cgo cas		.95																	.05								
sling ext load	.08	.87																	.05								
rappeling opn			.89													.08			.03								
paradrop			.18													.78	.01		.03								
unload		.44						.1					.02						.05				.39				
refuel rearm		.85						.15																			
lost			.25	.48											.01	.2	.06										
VHIRP														.02		.9	.05				.03						
500 AGL			.05	.05	.3										.01		.05		.04				.5				
detected			.5	.1															.4								
land OK																								.03		.97	
engaged		.21	.35					.2				.2									.02						.02
land damaged																								.1	.9		
drop ext load		.42	.48																.1								
land ext load		.34						.05				.2	.04										.37				
land EOM																		.88		.12							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 26. UH-1 TRANSITION TIME MATRIX (NIGHT JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1													.1											
tac nav				.2	.5		.1							.3	.3	.4	.3				.3		.5				
search					.5									.3	.3		.3										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.2						.1	.2			.1	.1			.1			.1								
load cgo/cas		.2																	.1								
sling ext load	.2	.2																	.1								
rappeling opn			.1													.1			.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel/rearm		.3						.3																			
lost			.1	.1											.1	.1	.1										
VHIRP														.1		.2	.1				.1						
500 AGL			.2	.2	.5										.1		.1		.1				.5				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										168	
shop																								24		48	
await msn	24								24																		
destroyed																											

Table 27. UH-1 TRANSITION PROBABILITY MATRIX (NIGHT MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo cas	sling ext load	rappeling opn	paradrop	unload	refuel rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.78												.02	.2											
tac T/O			.8													.2											
tac nav				.05	.44		.02							.01	.01	.13	.05				.02		.27				
search					.73									.01	.01		.25										
ID LZ						.54	.3			.03							.03					.1					
loiter							.98				.02																
land en route		.01						.17				.6	.02			.15			.05								
load cgo cas		.95																	.05								
sling ext load	.1	.85																	.05								
rappeling opn			.78													.2			.02								
paradrop			.08													.88	.01		.03								
unload		.49						.05					.02						.03				.41				
refuel rearm		.9						.1																			
lost			.2	.36											.01	.4	.03										
VHIRP														.01		.93	.03				.03						
500 AGL			.05	.15	.34										.01		.03		.02				.4				
detected			.6	.1															.3								
land OK																								.03		.97	
engaged		.24	.37					.18				.17									.02						.02
land damaged																								.1	.9		
drop ext load		.4	.5																.1								
land ext load		.39						.05				.15	.02										.39				
land EOM																		.92		.08							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 28. UH-1 TRANSITION TIME MATRIX (NIGHT MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1													.1											
tac nav				.3	.5		.1							.3	.3	.3	.4				.3		.5				
search					.5									.4	.3		.4										
ID LZ						.1	.1			.1							.1					.1					
loiter							.1				.1																
land en route		.1						.1				.1	.1			.1			.1								
load cgo/cas		.3																	.1								
sling ext load	.2	.2																	.1								
rappeling opn			.1													.1			.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.2	.1											.1	.1	.1										
VHIRP														.01		.2	.1				.1						
500 AGL			.2	.2	.5										.2		.2		.3				.5				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.2						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										168	
shop																								24		48	
await msn	24								24																		
destroyed																											

Table 29. UH-60 TRANSITION PROBABILITY MATRIX (DAY DESERT)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.88												.02	.1											
tac T/O			.9													.1											
tac nav				.05	.44		.01							.02	.01	.08	.1						.29				
search					.63									.01	.01		.35										
ID LZ						.48	.2			.04	.03						.05					.2					
loiter							.95				.05																
land en route		.01						.25	.23			.43	.06						.02								
load cgo cas		.98																	.02								
sling ext load	.1	[illegible]																	.02								
rappeling opn			.98																.02								
paradrop			.5													.44	.06										
unload		.43						.1					.05						.02				.4				
refuel rearm		.8						.2																			
lost			.3	.58			.02									.05	.05										
VHIRP														.01		.91	.05				.03						
500 AGL			.15	.05	.25										.01		.08		.03				.43				
detected			.52	.08															.4								
land OK																								.01	.2	.79	
engaged		.3	.4					.15				.08									.05						.02
land damaged																								.14	.86		
drop ext load		.33	.47																.2								
land ext load		.3						.05				.25	.07										.33				
land EOM																		.87		.13							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 30. UH-60 TRANSITION TIME MATRIX (DAY DESERT)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1													.1											
tac nav				.2	.3		.1							.2	.2	.2	.2						.3				
search					.2									.2	.2		.2										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.1			.1	.1						.1								
load cgo cas		.1																	.1								
sling ext load	.1	.1																	.1								
rappeling opn			.1																.1								
paradrop			.1													.1	.1										
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1			.1									.1	.1										
VHIRP														.1		.1	.1				.1						
500 AGL			.1	.2	.2										.1		.1		.1				.2				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										420	
shop																								48		72	
await msn	24								24																		
destroyed																											

Table 31. UH-60 TRANSITION PROBABILITY MATRIX (DAY JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.83												.02	.15											
tac T/O			.84												.01	.15											
tac nav				.05	.49		.01							.02	.01	.04	.07						.31				
search					.68									.01	.01		.3										
ID LZ						.47	.15			.08	.02						.03					.25					
loiter							.95				.05																
land en route		.01						.2	.2			.45	.05			.02			.07								
load cgo cas		.97																	.03								
sling ext load	.1	.87																	.03								
rappeling opn			.97																.03								
paradrop			.2													.71	.04		.05								
unload		.43						.1					.05						.03				.39				
refuel rearm		.8						.2																			
lost			.35	.54			.01							.01	.01	.05	.03										
VHIRP														.01		.95	.03				.01						
500 AGL			.1	.05	.2										.01		.03		.03				.58				
detected			.56	.09															.35								
land OK																								.01	.2	.79	
engaged		.28	.38					.15				.13									.05						.01
land damaged																								.14	.86		
drop ext load		.4	.45																.15								
land ext load		.27						.05				.3	.08										.3				
land EOM																		.89		.11							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 32. UH-60 TRANSITION TIME MATRIX (DAY JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1												.1	.1											
tac nav				.1	.2		.1							.1	.1	.1	.1						.3				
search					.2									.1	.1		.1										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.1			.1	.1			.1			.1								
load cgo cas		.1																	.1								
sling ext load	.1	.1																	.1								
rappeling opn			.1																.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1			.1							.1	.1	.1	.1										
VHIRP														.1		.1	.1				.1						
500 AGL			.1	.1	.2										.1		.1		.1				.3				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										420	
shop																								48		72	
await msn	24								24																		
destroyed																											

Table 33. UH-60 TRANSITION PROBABILITY MATRIX (DAY MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.78												.02	.2											
tac T/O			.8													.2											
tac nav				.05	.48		.01							.01	.01	.07	.05				.01		.31				
search					.73									.01	.01		.25										
ID LZ						.42	.2			.06	.01						.01					.3					
loiter							.95				.05																
land en route		.01						.16	.25			.45	.04			.05			.04								
load cgo cas		.97																	.03								
sling ext load	.1	.87																	.03								
rappeling opn			.87													.1			.03								
paradrop			.1													.85	.02		.03								
unload		.49						.05					.02						.03				.41				
refuel rearm		.8						.2																			
lost			.41	.4											.01	.15	.03										
VHIRP														.01		.91	.03				.05						
500 AGL			.1	.1	.25										.01		.03		.03				.48				
detected			.6	.1															.3								
land OK																								.01	.2	.79	
engaged		.24	.35					.2				.15									.05						.01
land damaged																								.14	.86		
drop ext load		.35	.5																.15								
land ext load		.32						.05				.2	.03										.4				
land EOM																		.92		.08							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 34. UH-60 TRANSITION TIME MATRIX (DAY MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1													.1											
tac nav				.1	.2		.1							.1	.1	.1	.1				.1		.2				
search					.2									.1	.1		.1										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.1			.1	.1			.1			.1								
load cgo cas		.1																	.1								
sling ext load	.1	.1																	.1								
rappeling opn			.1													.1			.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1											.1	.1	.1										
VHIRP														.1		.1	.1				.1						
500 AGL			.1	.1	.2										.1		.1		.1				.2				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										420	
shop																								48		72	
await msn	24								24																		
destroyed																											

Table 35. UH-60 TRANSITION PROBABILITY MATRIX (NIGHT DESERT)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.88												.02	.1											
tac T/O			.88												.02	.1											
tac nav				.09	.4		.01							.02	.01	.11	.07						.29				
search					.83									.01	.01		.15										
ID LZ						.45	.23			.02	.07						.08					.15					
loiter							.95				.05																
land en route		.02						.3	.05			.5	.03			.05			.05								
load cgo cas		.95																	.05								
sling ext load	.08	.87																	.05								
rappeling opn			.99																.01								
paradrop			.6													.37	.01		.02								
unload		.43						.1					.02						.05				.4				
refuel rearm		.85						.15																			
lost			.2	.56			.05									.15	.04										
VHIRP														.02		.91	.05				.02						
500 AGL			.12		.37										.01		.05		.03				.42				
detected			.4	.1															.5								
land OK																								.01	.2	.79	
engaged		.26	.42					.15				.11									.05						.01
land damaged																								.14	.86		
drop ext load		.35	.5																.15								
land ext load		.33						.05				.2	.05										.37				
land EOM																		.9		.1							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 36. UH-60 TRANSITION TIME MATRIX (NIGHT DESERT)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1												.1	.1											
tac nav				.2	.3		.1							.2	.2	.2	.2						.3				
search					.2									.2	.2		.2										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.1			.1	.1			.1			.1								
load cgo/cas		.1																	.1								
sling ext load	.1	.1																	.1								
rappeling opn			.1																.1								
paradrop		.	.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1			.1									.1	.1										
VHIRP														.1		.1	.1				.1						
500 AGL			.1		.2										.1		.1		.1				.2				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										420	
shop																								48		72	
await msn	24								24																		
destroyed																											

Table 37. UH-60 TRANSITION PROBABILITY MATRIX (NIGHT JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.83												.02	.15											
tac T/O			.85													.15											
tac nav				.05	.47		.01							.02	.01	.09	.03						.32				
search					.86									.01	.01		.12										
ID LZ						.45	.22			.04	.04						.05					.2					
loiter							.95				.05																
land en route		.02						.26	.05			.51	.03			.05			.08								
load cgo cas		.95																	.05								
sling ext load	.08	.87																	.05								
rappeling opn			.89													.08			03								
paradrop			.18													.79	.01		.02								
unload		.44						.1					.02						.05				.39				
refuel rearm		.85						.15																			
lost			.25	.52											.01	.2	.02										
VHIRP														.02		.94	.02				.02						
500 AGL			.05	.05	.35										.01		.02		.02				.5				
detected			.5	.1															.4								
land OK																								.01	.2	.79	
engaged		.21	.34					.2				.19									.05						.01
land damaged																								.14	.86		
drop ext load		.42	.48																.1								
land ext load		.34						.05				.2	.04										.37				
land EOM																		.92		.08							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 38. UH-60 TRANSITION TIME MATRIX (NIGHT JUNGLE)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T O			.1												.1	.1											
tac T O			.1													.1											
tac nav				.1	.2		.1							.1	.1	.1	.1						.3				
search					.2									.1	.1		.1										
ID LZ						.1	.1			.1	.1						.1					.1					
loiter							.1				.1																
land en route		.1						.1	.1			.1	.1			.1			.1								
load cgo cas		.1																	.1								
sling ext load	.1	.1																	.1								
rappeling opn			.1													.1			.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1											.1	.1	.1										
VHIRP														.1		.1	.1				.1						
500 AGL			.1	.2	.2										.1		.1		.1				.3				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										420	
shop																								48		72	
await msn	24								24																		
destroyed																											

Table 39. UH-60 TRANSITION PROBABILITY MATRIX (NIGHT MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.78												.02	.2											
tac T/O			.8													.2											
tac nav				.05	.45		.01							.01	.0[illegible]	.14	.03						.3				
search					.86									.01	.01		.12										
ID LZ						.5	.24			.03							.03					.2					
loiter							.98				.02																
land en route		.01						.15	.02			.6	.02			.15			.05								
load cgo cas		.95																	.05								
sling ext load	.1	.85																	.05								
rappeling opn			.78													.2			.02								
paradrop			.08													.89	.01		.02								
unload		.49						.05					.02						.03				.41				
refuel rearm		.9						.1																			
lost			.25	.4											.01	.33	.01										
VHIRP														.01		.97	.01				.01						
500 AGL			.05	.15	.37										.01		.01		.01				.4				
detected			.6	.1															.3								
land OK																								.01	.2	.79	
engaged		.21	.34					.2				.19									.05						.01
land damaged																								.14	.86		
drop ext load		.4	.5																.1								
land ext load		.39						.05				.15	.02										.39				
land EOM																		.95		.05							
depot																										1.	
shop																								.02		.98	
await msn	.9								.1																		
destroyed																											1.

Table 40. UH-60 TRANSITION TIME MATRIX (NIGHT MOUNTAIN)

	initial T/O	tac T/O	tac nav	search	ID LZ	loiter	land en route	load cgo/cas	sling ext load	rappeling opn	paradrop	unload	refuel/rearm	lost	VHIRP	500 AGL	detected	land OK	engaged	land damaged	drop ext load	land ext load	land EOM	depot	shop	await msn	destroyed
initial T/O			.1												.1	.1											
tac T/O			.1													.1											
tac nav				.1	.2		.1							.1	.1	.1	.1						.3				
search					.2									.1	.1		.1										
ID LZ						.1	.1			.1							.1					.1					
loiter							.1				.1																
land en route		.1						.1	.1			.1	.1			.1			.1								
load cgo cas		.1																	.1								
sling ext load	.2	.2																	.1								
rappeling opn			.1													.1			.1								
paradrop			.1													.1	.1		.1								
unload		.1						.1					.1						.1				.1				
refuel rearm		.3						.3																			
lost			.1	.1											.1	.1	.1										
VHIRP														.1		.2	.1				.1						
500 AGL			.1	.1	.2										.1		.1		.1				.3				
detected			.1	.1															.1								
land OK																											
engaged		.1	.1					.1				.1									.1						.1
land damaged																											
drop ext load		.1	.1																.1								
land ext load		.1						.1				.1	.1										.1				
land EOM																		.1		.1							
depot																										42	
shop																								48		72	
await msn	24								24																		
destroyed																											

APPENDIX B. STATE SPACE DESCRIPTION

initial T/O	the initial helicopter takeoff signaling the start of a flight mission
tac T/O	a tactical takeoff performed in a hostile environment using cover and concealment to mask movement
tac nav	tactical flight during which a helicopter employs one of three flight profiles: Nap-of-the-Earth (reduced speed and as close to the ground as ambient lighting conditions permit), Contour (conforming to terrain contours at moderate speeds) and Low Level (flying rapidly at a low, constant altitude which avoids all obstacles), while navigating through the intended flight path [Ref. 36: pp. 6-2-6-3]
search	a mission requiring aerial reconnaissance or location of a geographic reference or force
ID LZ	identifying a planned landing or drop zone
loiter	hovering or flying about a vicinity awaiting some action such as aerial artillery preparation of an enemy occupied landing zone
land en route	a landing, forced or voluntary, prior to mission termination
load cgo/cas	internally loading cargo and/or casualties within the helicopter
sling ext load	all preparation for an external load operation preceding the actual takeoff
rappeling opn	a delivery operation during which trained personnel descend from ropes anchored from a hovering helicopter [Ref. 36: p. 11-1]
paradrop	delivery of equipment and/or personnel from a helicopter by parachute
unload	evacuation of cargo, passengers and casualties from the internal helicopter compartment
refuel-rearm	replenishing the helicopter's basic load of M60 machinegun ammunition and fuel, often while the aircraft engine remains at idle
lost	self explanatory
VHIRP	vertical helicopter instrument flight rules recovery procedure: a procedure initiated when a helicopter flying with visual reference to the horizon, inadvertently encounters obscuration (clouds, dust, snow, sand) and must transition to instrument flight
500 AGL	flight at or above 500 feet above ground level
detected	detected by enemy forces
land OK	after executing a successful end-of-mission landing, the post flight inspection detects no combat related damage
engaged	engaged by enemy forces
land damaged	after executing a successful end-of-mission landing, post flight inspection reveals combat related damage

drop ext load	emergency jettison of external load
land ext load	successful termination of an external load operation
land EOM	successful mission termination at launch facility
depot	a condition in which extensive repair or maintenance is accomplished
shop	a condition in which intermediate repair or maintenance is accomplished
await msn	a condition during which a helicopter sustains daily inspections and awaits the subsequent mission launch
destroyed	aircraft is economically unrepairable

APPENDIX C. APL COMPUTATIONAL PROGRAM

```
      ∇ WARP ARRAY
[1]   W←+/ARRAY[⍳12;;]×ARRAY[12+⍳12;;]
[2]   I← 27 27 ρ1,27ρ0
[3]   Q← 12 26 26 ρ0
[4]   Q[1;;]←⌹(¯1 ¯1 ↓(I-ARRAY[1;;]))
[5]   Q[2;;]←⌹(¯1 ¯1 ↓(I-ARRAY[2;;]))
[6]   Q[3;;]←⌹(¯1 ¯1 ↓(I-ARRAY[3;;]))
[7]   Q[4;;]←⌹(¯1 ¯1 ↓(I-ARRAY[4;;]))
[8]   Q[5;;]←⌹(¯1 ¯1 ↓(I-ARRAY[5;;]))
[9]   Q[6;;]←⌹(¯1 ¯1 ↓(I-ARRAY[6;;]))
[10]  Q[7;;]←⌹(¯1 ¯1 ↓(I-ARRAY[7;;]))
[11]  Q[8;;]←⌹(¯1 ¯1 ↓(I-ARRAY[8;;]))
[12]  Q[9;;]←⌹(¯1 ¯1 ↓(I-ARRAY[9;;]))
[13]  Q[10;;]←⌹(¯1 ¯1 ↓(I-ARRAY[10;;]))
[14]  Q[11;;]←⌹(¯1 ¯1 ↓(I-ARRAY[11;;]))
[15]  Q[12;;]←⌹(¯1 ¯1 ↓(I-ARRAY[12;;]))
[16]  N← 12 1 26 ↑Q
[17]  N← 12 26 ρN
[18]  W← 12 26 ↑W
[19]  MOE3←+/N×W
[20]  NN←N
[21]  WW←W
[22]  NN[;24]←NN[;26]
[23]  WW[;24]←WW[;26]
[24]  NN← 12 24 ↑NN
[25]  WW← 12 24 ↑WW
[26]  MOE4←+/NN×WW
[27]  MOE1←12ρ0
[28]  MOE1[⍳6]←24×(N[⍳6;1]×2420)÷MOE3[⍳6]
[29]  MOE1[6+⍳6]←24×(N[6+⍳6;1]×3360)÷MOE3[6+⍳6]
[30]  MOE2←12ρ0
[31]  MOE2[⍳6]←24×(N[⍳6;1]×11)÷MOE3[⍳6]
[32]  MOE2[6+⍳6]←24×(N[6+⍳6;1]×15)÷MOE3[6+⍳6]
[33]  MOE5←MOE3-MOE4
[34]  MOE6←(+/(12 23 ↑N)×(12 23 ↑W))÷N[;1]
[35]  MOE7←N[;1]
[36]  MOE8←(MOE6×MOE7)÷MOE3
[37]  C←12ρ0
[38]  C[⍳6]←(N[⍳6;20]×1800.33)+(Q[⍳6;18;24]×4200)
[39]  C[6+⍳6]←(N[6+⍳6;20]×5603.17)+Q[6+⍳6;18;25]×122
[40]  C[6+⍳6]←C[6+⍳6]+Q[6+⍳6;18;24]×24500
[41]  CR←12ρ0
[42]  CR[⍳6]←C[⍳6]÷(N[⍳6;1]×2420)
[43]  CR[6+⍳6]←C[6+⍳6]÷(N[6+⍳6;1]×3360)
[44]  MOE1[⍳6]
[45]  MOE1[6+⍳6]
[46]  MOE2[⍳6]
[47]  MOE2[6+⍳6]
[48]  MOE3[⍳6]÷24
[49]  MOE3[6+⍳6]÷24
[50]  MOE4[⍳6]÷24
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[51]   MOE4[6+⍳6]÷24
[52]   MOE5[⍳6]÷24
[53]   MOE5[6+⍳6]÷24
[54]   MOE6[⍳6]
[55]   MOE6[6+⍳6]
[56]   MOE7[⍳6]
[57]   MOE7[6+⍳6]
[58]   MOE8[⍳6]
[59]   MOE8[6+⍳6]
[60]   CR[⍳6]
[61]   CR[6+⍳6]
[62]   100×MOE1[⍳6]÷MOE1[6+⍳6]
[63]   100×(+/MOE1[⍳6])÷(+/MOE1[6+⍳6])
[64]   100×MOE1[6+⍳6]÷MOE1[⍳6]
[65]   100×(+/MOE1[6+⍳6])÷(+/MOE1[⍳6])
[66]   100×MOE3[6+⍳6]÷MOE3[⍳6]
[67]   100×(+/MOE3[6+⍳6])÷(+/MOE3[⍳6])
[68]   100×MOE4[6+⍳6]÷MOE4[⍳6]
[69]   100×(+/MOE4[6+⍳6])÷(+/MOE4[⍳6])
[70]   100×MOE5[6+⍳6]÷MOE5[⍳6]
[71]   100×(+/MOE5[6+⍳6])÷(+/MOE5[⍳6])
[72]   100×MOE6[⍳6]÷MOE6[6+⍳6]
[73]   100×(+/MOE6[⍳6])÷(+/MOE6[6+⍳6])
[74]   100×MOE7[6+⍳6]÷MOE7[⍳6]
[75]   100×(+/MOE7[6+⍳6])÷(+/MOE7[⍳6])
[76]   100×MOE8[⍳6]÷MOE8[6+⍳6]
[77]   100×(+/MOE8[⍳6])÷(+/MOE8[6+⍳6])
[78]   100×CR[6+⍳6]÷CR[⍳6]
[79]   100×(+/CR[6+⍳6])÷(+/CR[⍳6])
       ∇
```

APPENDIX D. METHODOLOGY FOR MATRIX MANIPULATION

The following example illustrates the sequential methodology used to generate the model's MOE.

- Create the transition probability matrix, P, and the sojourn time matrix, T.

Table 41. EXAMPLE P MATRIX

	start	fly	unload cargo	shot at	unload troops	end	crash
start		.98		.01			.01
fly			.2	.02	.28	.48	.02
unload cargo		.98		.02			
shot at		.7	.02		.04	.19	.05
unload troops		.98		.02			
end	1.0						
crash							1.0

Table 42. EXAMPLE T MATRIX

	start	fly	unload cargo	shot at	unload troops	end	crash
start		.1		.1			.1
fly			.9	.5	.9	.9	.5
unload cargo		.2		.1			
shot at		.1	.1		.1	.1	.1
unload troops		.1		.1			
end	0.0						
crash							0.0

The matrix axes must include conspicuous start and end segments in order to determine the number of missions completed prior to loss. The aircraft loss segment (crash), represented by an *absorbing state*, is likewise essential; otherwise, the aircraft would fly forever. The sojourn time matrix records the expected useful mission time associated with each transition. Zero is entered for any transition from an absorbing state.

- Calculate w_i, the expected useful mission time for each segment.

$$w_i = \sum_j p_{ij} t_{ij}, \qquad \forall i$$

$$= [\ .10\ .88\ .20\ .10\ .10\ \ 0.0\ 0.0\ ]$$

- Partition P into four sub-matrices:
  - Q : transient → transient transitions
  - R : transient → absorbing transitions
  - I : absorbing → absorbing transitions
  - $\emptyset$: no transitions

$$P = \begin{vmatrix} Q & R \\ \emptyset & I \end{vmatrix}$$

$$= \begin{vmatrix} 0.0 & .98 & 0.0 & .01 & 0.0 & 0.0 & .01 \\ 0.0 & 0.0 & .20 & .02 & .28 & .48 & .02 \\ 0.0 & .98 & 0.0 & .02 & 0.0 & 0.0 & 0.0 \\ 0.0 & .70 & .02 & 0.0 & .04 & .19 & .05 \\ 0.0 & .98 & 0.0 & .02 & 0.0 & 0.0 & 0.0 \\ 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{vmatrix}$$

If P does not have all transient segments in the upper-left corner and absorbing segments in the lower right, exchange *rows and columns* in P to make it so prior to partitioning the matrix.

- Calculate the Markov chain's fundamental matrix, $(I-Q)^{-1}$ [Ref. 37: p. 760].

Where $N = (I-Q)^{-1}$

$$N = \begin{vmatrix} 19 & 37 & 7 & 1 & 10 & 18 \\ 18 & 38 & 8 & 1 & 11 & 18 \\ 18 & 38 & 9 & 1 & 11 & 18 \\ 18 & 36 & 7 & 2 & 10 & 18 \\ 18 & 38 & 8 & 1 & 12 & 18 \\ 19 & 37 & 7 & 1 & 10 & 19 \end{vmatrix} \quad \text{(with } n_{ij} \text{ rounded to integer values)}$$

N contains n_{ij}, the expected number of times that state j is visited, starting from state i. Thus, by referencing the start segment, i = 1, one can determine the expected number of visits to each segment before absorption (crash).

Table 43. FIRST LINE FROM N MATRIX.

starts	flights	unload cargos	shot at	unload troops	ends
19	37	7	1	10	18

- Using starting segment i = 1, n_{ij} and w_j, calculate the expected (total useful mission) lifetime.

$$L = \sum_{j \in \text{transient segments}} n_{ij}\, w_j = 36.98 \quad \text{(MOE \#3)}$$

- As a check of the model, using n_{11} compute the average mission length.

$$M = \frac{L}{n_{11} - 0.5} = \frac{36.98}{19 - 0.5} \approx 2,$$

Approximating the last mission as half the length of an average mission, the two hour mission length calculated is well within the aircrafts' capabilities.

- Calculate the remaining MOE.
  - Amount of cargo delivered prior to aircraft destruction (MOE #1) = (7) x (Cargo carrying capacity of aircraft)
  - Number of soldiers moved prior to aircraft destruction (MOE #2) = (10) x (Troop carrying capacity of aircraft)

APPENDIX E. DATA RESULTS WITH UH-1 BIAS

Table 44. MEASURES OF EFFECTIVENESS #1 THROUGH #8

MOE	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
Max Cargo Delivered Daily	UH-1	1279.0	1369.6	1395.7	1345.1	1409.0	1494.4
	UH-60	1159.7	1203.1	1288.3	1210.4	1295.2	1389.1
Max Passengers Delivered Daily	UH-1	5.8	6.2	6.3	6.1	6.4	6.8
	UH-60	5.2	5.4	5.8	5.4	5.8	6.2
Total Acft Life (days)	UH-1	154.3	233.5	480.1	204.7	352.2	473.4
	UH-60	693.7	1599.4	2144.7	1030.9	1474.9	2011.9
Acft Useful Life (days)	UH-1	93.8	152.1	322.6	134.2	240.7	344.8
	UH-60	272.1	649.5	925.5	429.3	652.3	954.4
Acft Main/Repair Time (days)	UH-1	60.5	81.4	157.5	70.5	111.5	128.7
	UH-60	421.6	949.9	1219.1	601.6	822.6	1057.6
Avg Msn Length (hours)	UH-1	1.8	1.7	1.8	2.2	2.0	2.0
	UH-60	1.5	1.3	1.1	1.5	1.2	1.2
Number of Mission Launches	UH-1	81.6	132.1	276.9	113.8	205.1	292.4
	UH-60	239.4	572.7	822.3	371.4	568.5	831.8
Flight As a Percent Acft Life	UH-1	.040	.040	.043	.051	.048	.052
	UH-60	.022	.019	.018	.022	.020	.021

APPENDIX F. DATA RESULTS WITH UH-60 BIAS

Table 45. MEASURES OF EFFECTIVENESS #1 THROUGH #8

MOE	Acft	Day			Night		
		Desert	Jungle	Mount	Desert	Jungle	Mount
Max Cargo Delivered Daily	UH-1	1279.0	1369.6	1395.7	1345.1	1409.0	1494.4
	UH-60	1366.3	1410.5	1497.2	1365.0	1444.6	1529.2
Max Passengers Delivered Daily	UH-1	5.8	6.2	6.3	6.1	6.4	6.8
	UH-60	6.2	6.3	6.7	6.1	6.4	6.8
Total Acft Life (days)	UH-1	154.3	233.5	480.1	204.7	352.2	473.4
	UH-60	588.8	1364.3	1845.5	914.1	1322.4	1827.6
Acft Useful Life (days)	UH-1	93.8	152.1	322.6	134.2	240.7	344.8
	UH-60	272.1	649.5	925.5	429.3	652.3	954.4
Acft Main/Repair Time (days)	UH-1	60.5	81.4	157.5	70.5	111.5	128.7
	UH-60	316.7	714.8	920.0	484.8	670.1	873.3
Avg Msn Length (hours)	UH-1	1.8	1.7	1.8	2.2	2.0	2.0
	UH-60	1.5	1.3	1.1	1.5	1.2	1.2
Number of Mission Launches	UH-1	81.6	132.1	276.9	113.8	205.1	292.4
	UH-60	239.4	572.7	822.3	371.4	568.5	831.8
Flight As a Percent Acft Life	UH-1	.040	.040	.043	.051	.048	.052
	UH-60	.025	.022	.020	.025	.022	.024

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